Rare beauty decays at LHCb

Francesco Dettori

On behalf of the LHCb Collaboration

CERN European Organization for Nuclear Research

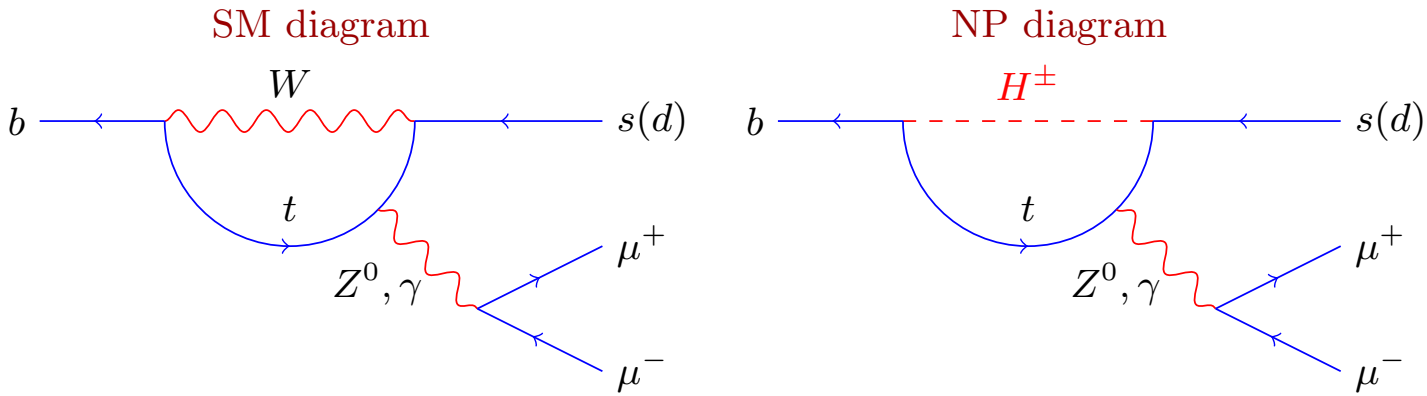
Rencontres de Moriond
QCD and High Energy Interactions
La Thuile, Italy, March 21-28, 2015

Outline

- Introduction
- Observation of the $B_s^0 \to \mu^+\mu^-$ decay
- Test of lepton universality using $B^+ \to K^+\ell^+\ell^-$ decays
- Angular analysis of $B_d^0 \to K^*e^+e^-$ decays
- Angular analysis of $B_d^0 \to K^*\mu^+\mu^-$ decays
- Conclusions

Rare decays

- FCNC are strongly suppressed in the SM: only loops + GIM mechanism
- Any new particle generating new diagrams can change the amplitudes



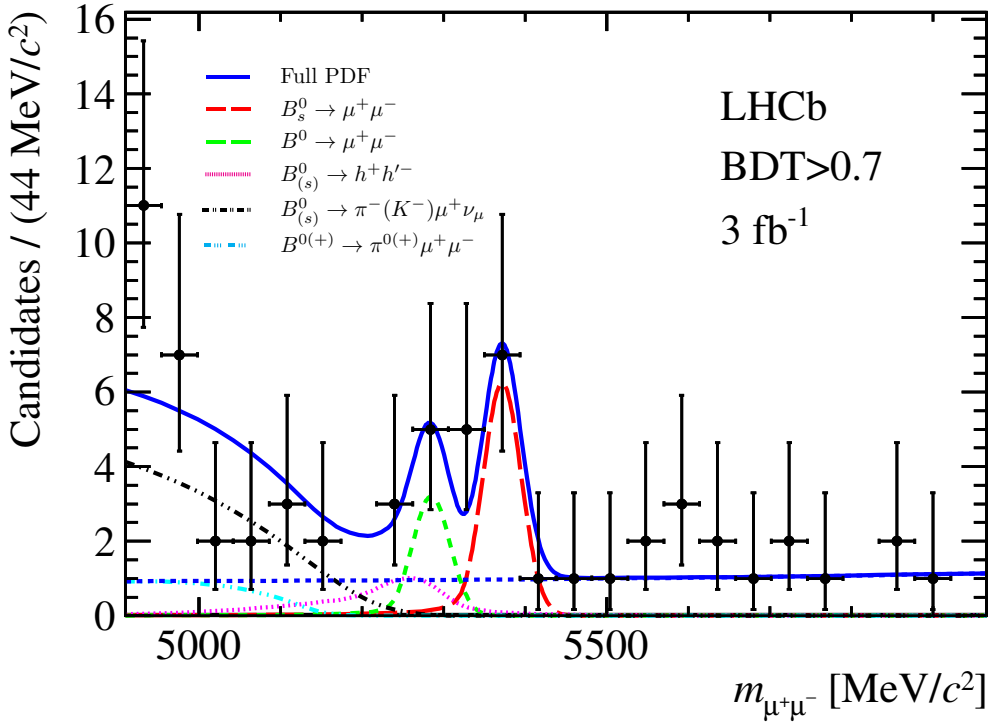
- Generic description though effective hamiltonian

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{\text{tb}} V_{\text{tq}}^* \sum_i (C_i \mathcal{O}_i + C_i' \mathcal{O}_i')$$

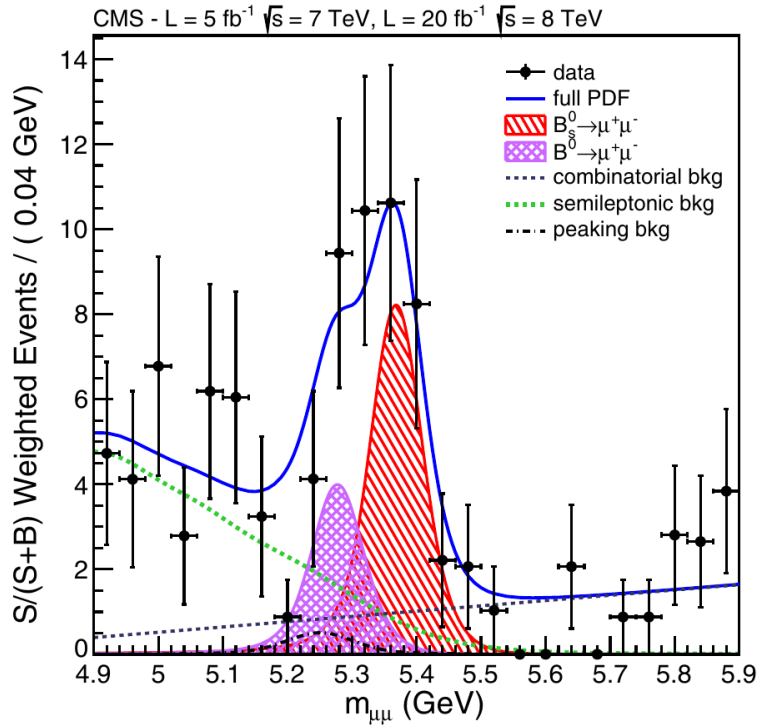
- Wilson coefficients $C^{(\prime)}$ encode the left- (right)-handed short distance physics of the corresponding operator $\mathcal{O}^{(\prime)}$
- NP can enter with new operators or modifying the coefficients

Observation of the rare $B_s^0 \to \mu^+\mu^-$ decay from the combined analysis of LHCb and CMS data

[LHCb - Phys. Rev. Lett. 111, 101805 (2013)]

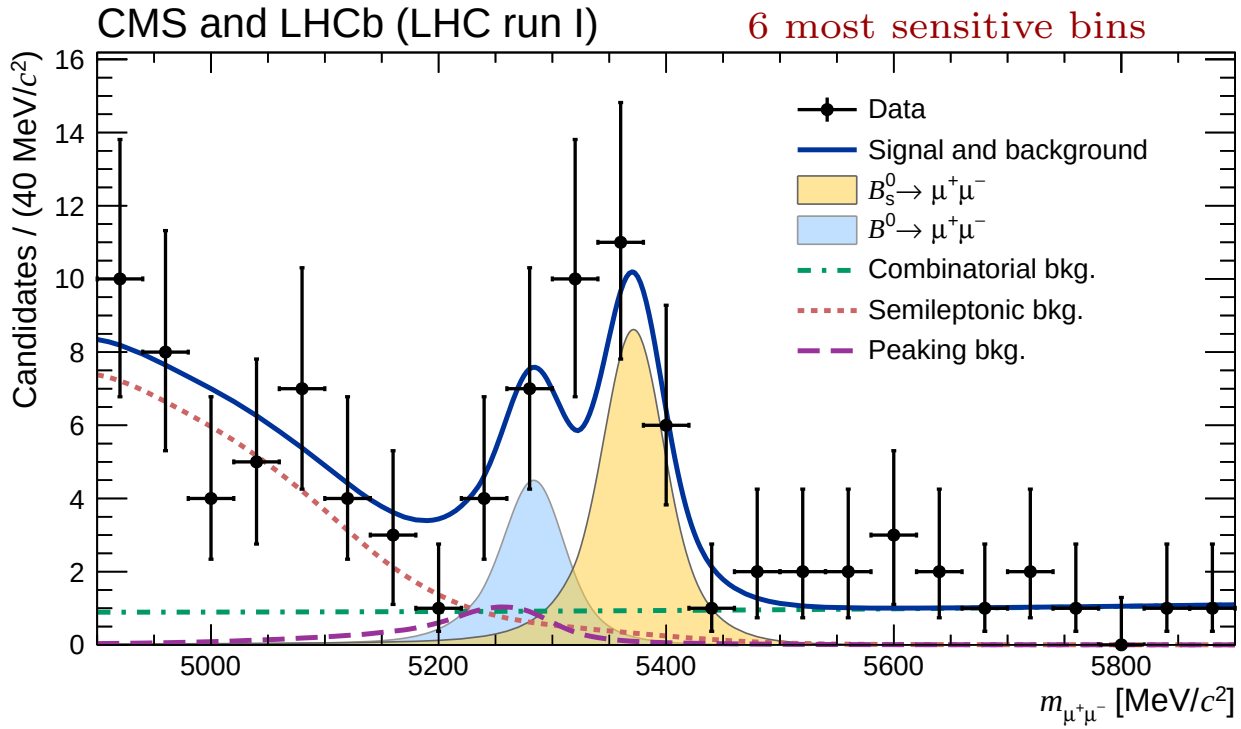


[CMS - Phys. Rev. Lett. 111, 101804 (2013)]



- $B_s^0 \to \mu^+\mu^-$ golden channel for C_{10} and (pseudo)-scalar operators
- Precisely predicted as fully leptonic and ultra rare due to helicity suppression
- Seen by both LHCb and CMS with LHC RunI data
- Full combination of the two experiments analysis

Combination results



$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = 2.8^{+0.7}_{-0.6} \times 10^{-9} \quad (6.2\sigma \text{ significance})$$

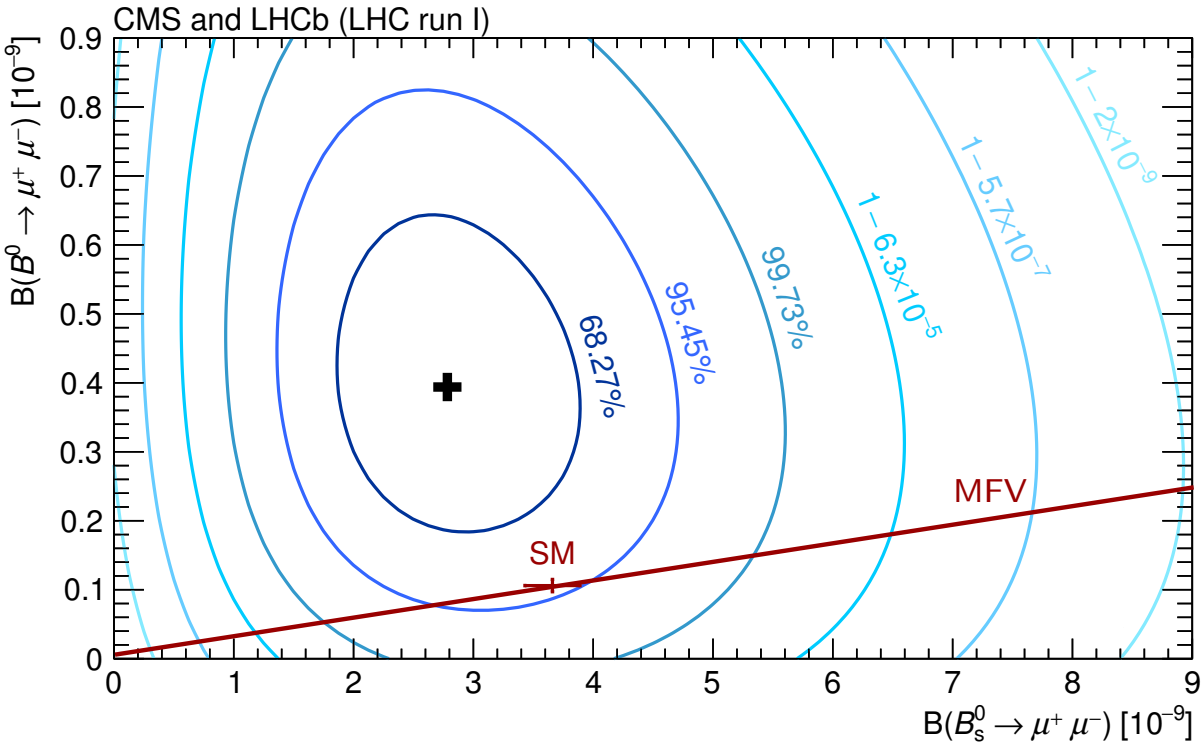
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = 3.9^{+1.6}_{-1.4} \times 10^{-10} \quad (3.0\sigma \text{ significance}^*)$$

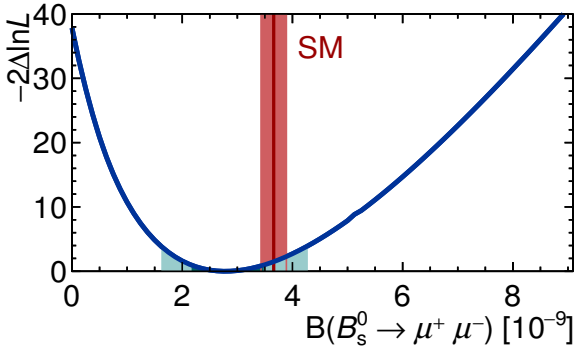
Which represent the first observation of the $B_s^0 \to \mu^+\mu^-$ decay and a first evidence for the $B^0 \to \mu^+\mu^-$ decay.

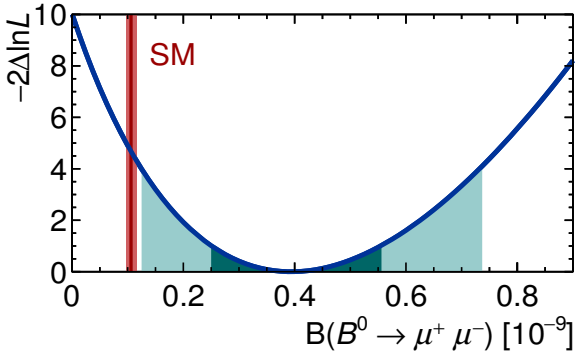
*From the Feldman Cousins method

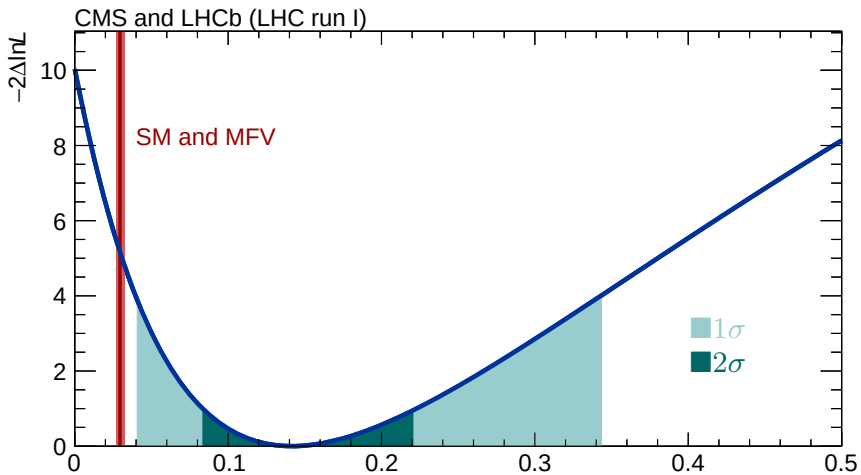
[hep-ex/1411.4413] - Accepted by Nature

$B^0_{d,s} \to \mu^+\mu^-$: confidence intervals









Measurement of the ratio:

$$\mathcal{R} = 0.14^{+0.08}_{-0.06}$$

compatible with the SM prediction $\mathcal{R} = 0.0295^{+0.0028}_{-0.0025}$ at the 2.3σ level

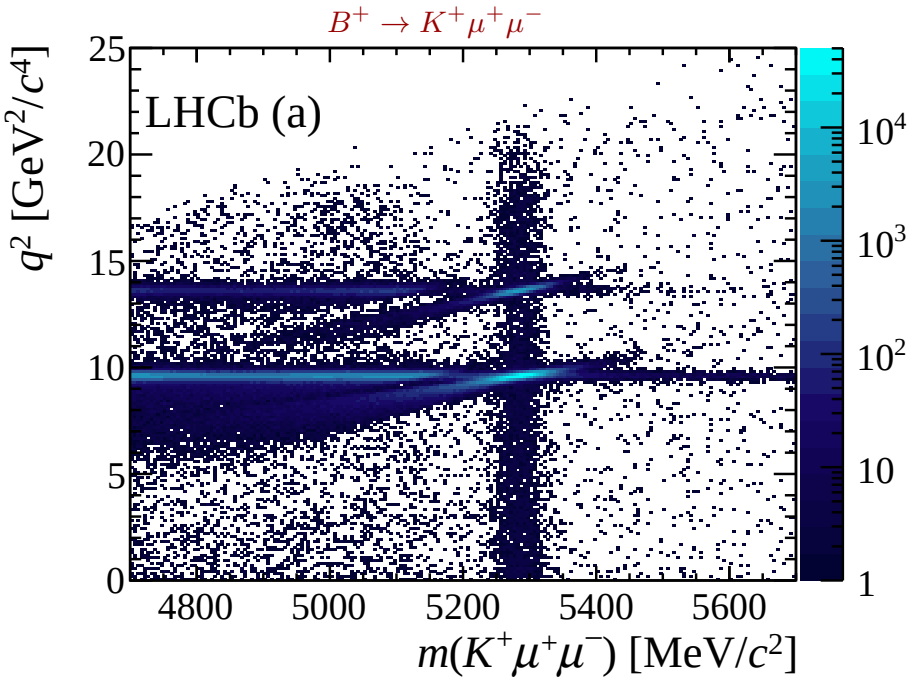
[hep-ex/1411.4413] - Accepted by Nature

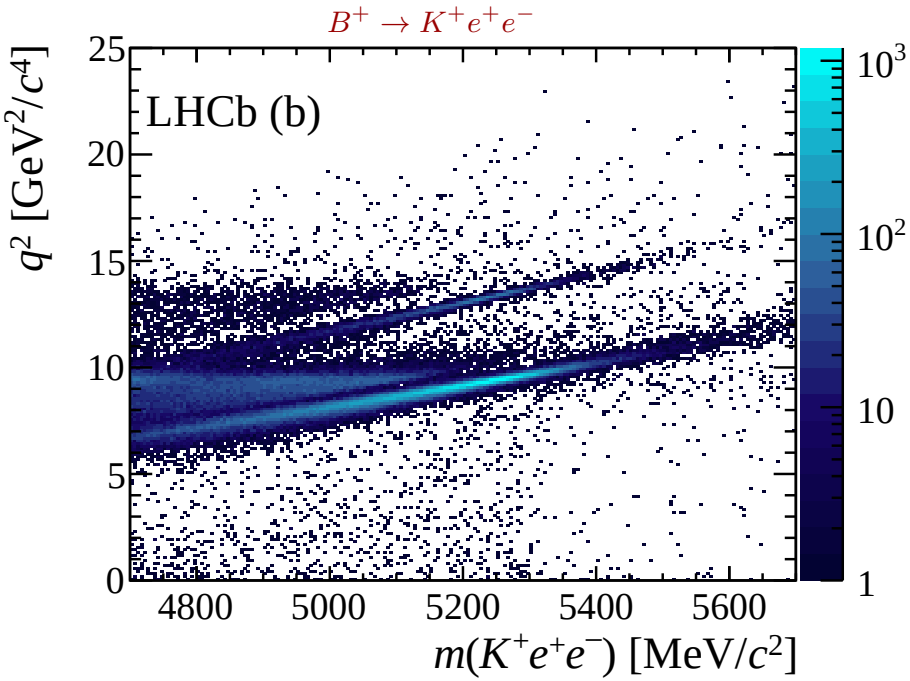
Test of lepton universality using $B^+ \to K^+\ell^+\ell^-$ decays

- Ratio of branching fractions of $B^+ \to K^+e^+e^-$ and $B^+ \to K^+\mu^+\mu^-$ sensitive to lepton universality

$$R_K = \frac{\int_{q^2_{min}}^{q^2_{max}} \frac{d\Gamma[\mathcal{B}(B^+\to K^+\mu^+\mu^-)]}{dq^2} dq^2}{\int_{q^2_{min}}^{q^2_{max}} \frac{d\Gamma[\mathcal{B}(B^+\to K^+e^+e^-)]}{dq^2} dq^2} = \left(\frac{N_{K\mu\mu}}{N_{Kee}}\right)\left(\frac{N_{J/\psi(ee)K}}{N_{J/\psi(\mu\mu)K}}\right)\left(\frac{\varepsilon_{Kee}}{\varepsilon_{K\mu\mu}}\right)\left(\frac{\varepsilon_{J/\psi(ee)K}}{\varepsilon_{J/\psi(\mu\mu)K}}\right)$$

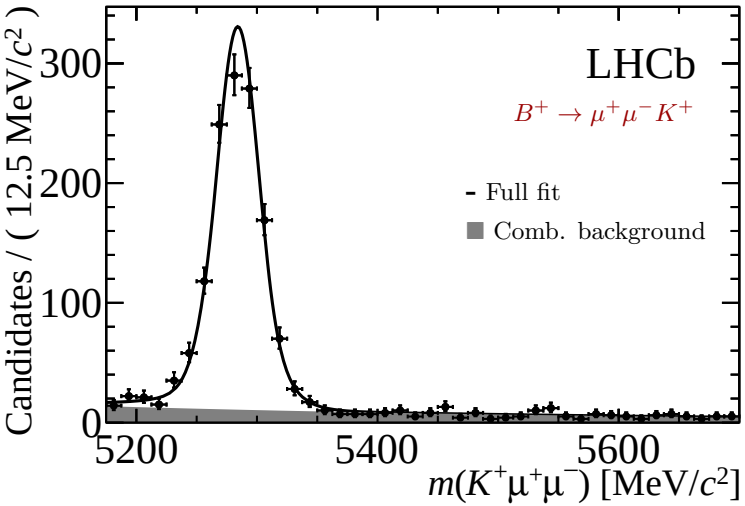
- SM prediction is $R_K = 1$ with an uncertainty of $\mathcal{O}(10^{-3})$
- Measurement relative to resonant $B \to J\psi K$ modes

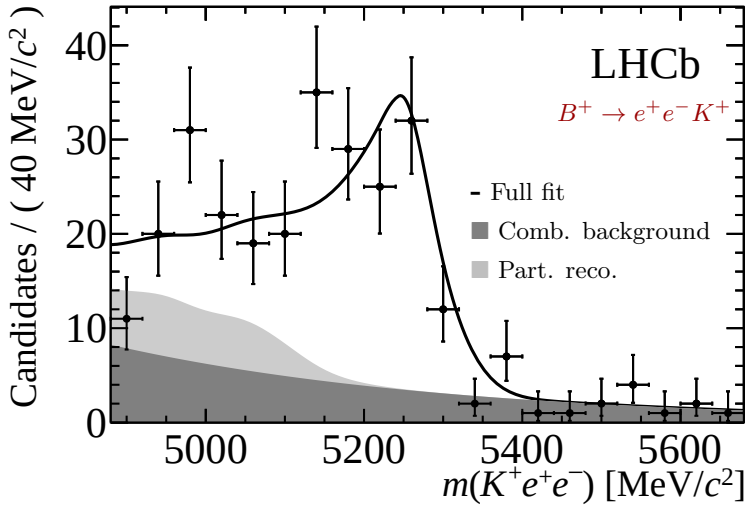




[Phys. Rev. Lett. 113, 151601]

Test of lepton universality using $B^+ \to K^+\ell^+\ell^-$ decays





$q^2 \in [1,6]\text{GeV}^2/\text{c}^4$

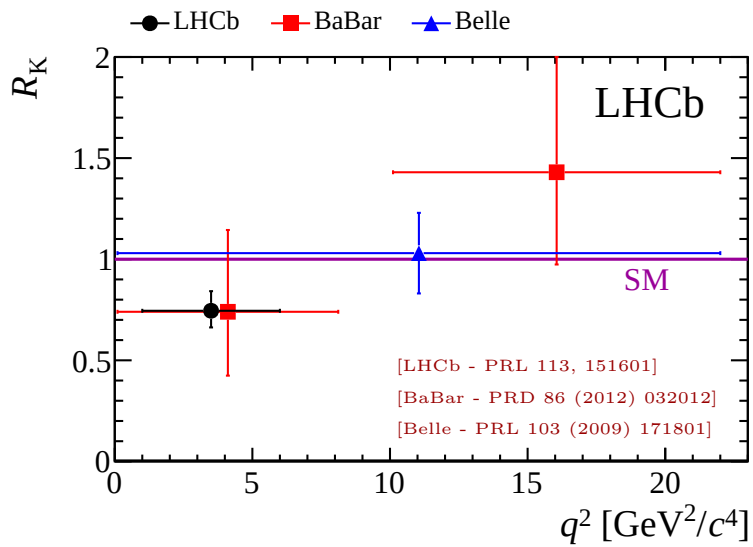
Electron Trigger

[Phys. Rev. Lett. 113, 151601]

The combination of the various trigger channels gives:

$$R_K = 0.745^{+0.090}_{-0.074}(\text{stat}) \pm 0.036(\text{syst})$$

Most precise measurement to date, compatible with SM at 2.6σ level



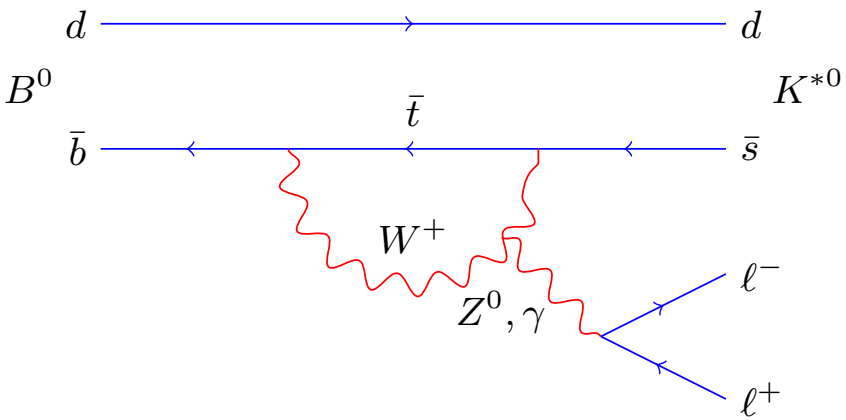
The branching fraction of $B^+ \to e^+e^- K^+$ is measured as

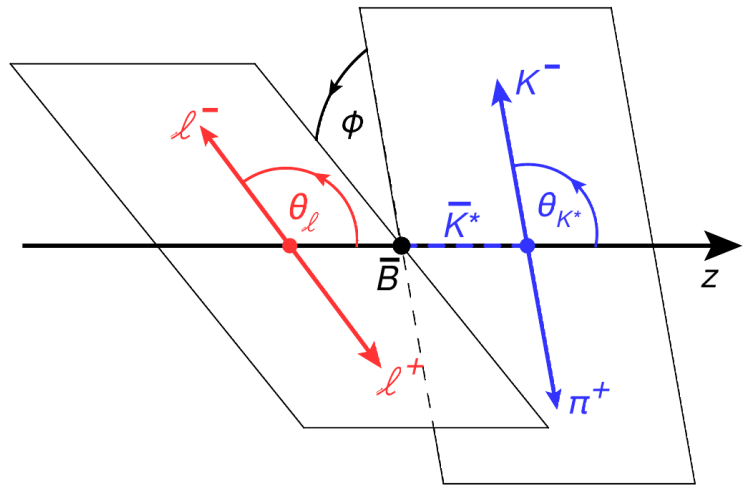
$\mathcal{B}(B^+ \to e^+e^- K^+) = 1.56^{+0.19}_{-0.15}(\text{stat})^{+0.06}_{-0.05}(\text{syst}) \times 10^{-7}$

well compatible with SM predictions

Angular analysis of $B^0_d \to K^*\ell^+\ell^-$ decays

- $b \to s$ transition with vector in the final state
- Final state described by $q^2 = m^2_{\mu\mu}$ and three angles $\Omega = (\theta_\ell, \theta_K, \phi)$
- F_L, A_{FB}, S_i sensitive to $C_7^{(\prime)}$ $C_9^{(\prime)}$ $C_{10}^{(\prime)}$

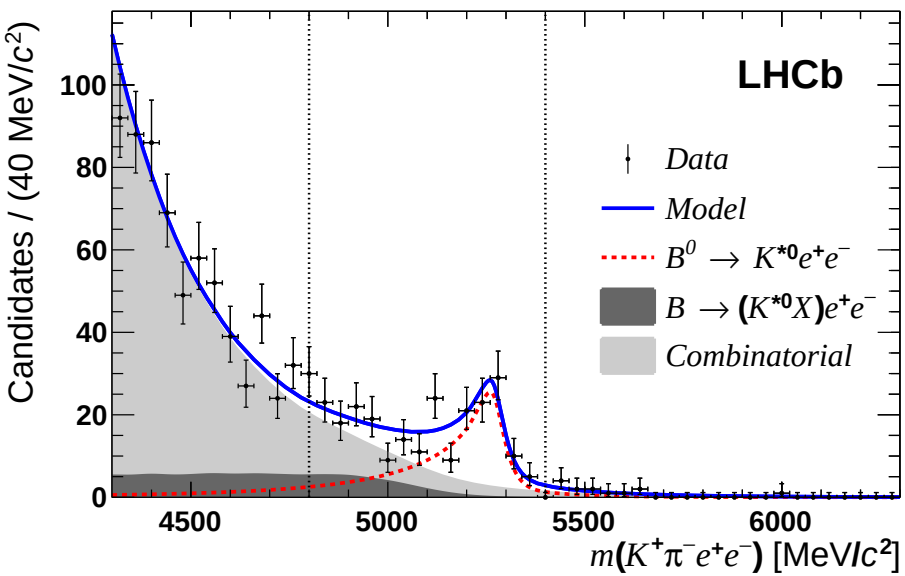


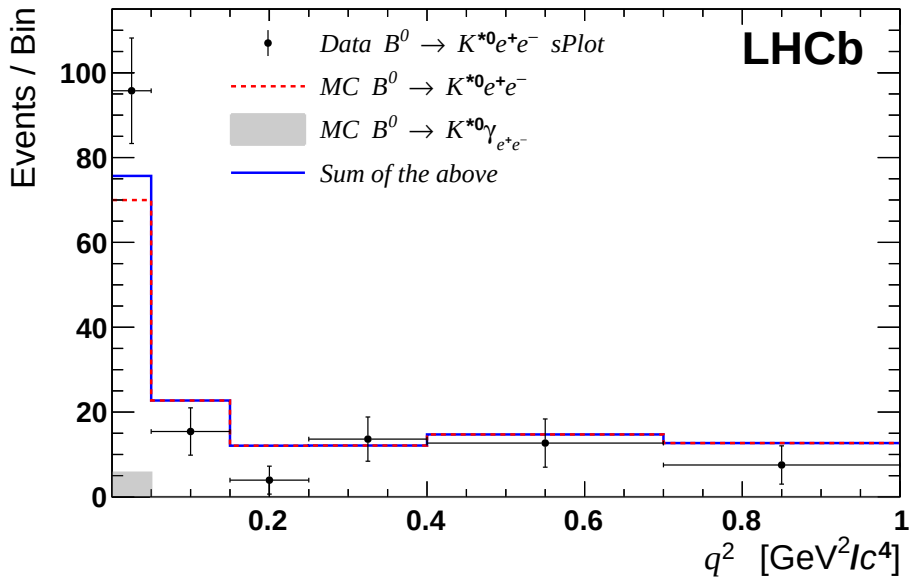


$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\vec{\Omega}} = \frac{9}{32\pi}\Big[\tfrac{3}{4}(1-F_\mathrm{L})\sin^2\theta_K + F_\mathrm{L}\cos^2\theta_K + \tfrac{1}{4}(1-F_\mathrm{L})\sin^2\theta_K\cos 2\theta_\ell$$
$$- F_\mathrm{L}\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi$$
$$+ S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi$$
$$+ \tfrac{4}{3}A_\mathrm{FB}\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi$$
$$+ S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$

Angular analysis of $B^0_d \to K^* e^+ e^-$ decays

- Angular analysis of $B^0_d \to K^* e^+ e^-$ at very low q^2 ($\in [0.002, 1.120] \mathrm{GeV}^2/\mathrm{c}^4$)
- Folded angular observables ($\phi = \phi + \pi$ if $\phi < 0$)
- Measurement of F_L, $A_T^{(2)}$, $A_T^{(\mathrm{Im})}$, $A_T^{(\mathrm{Re})}$, † sensitive to C_7' as $q^2 \to 0$

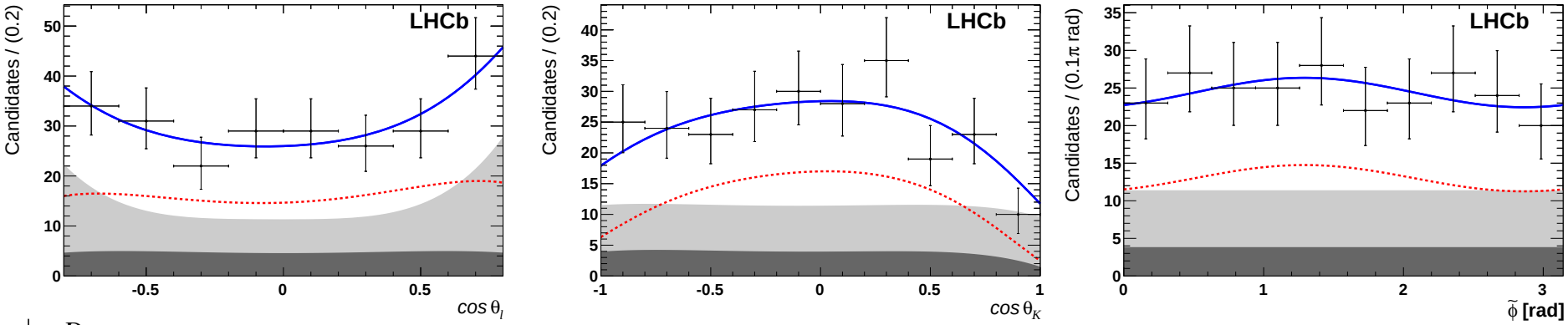


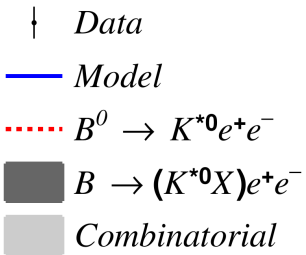


† $A_T^{(\mathrm{Re})} = \frac{4}{3} A_{FB}/(1-F_L)$, $A_T^{(2)} = \frac{1}{2} S_3/(1-F_L)$ and $A_T = \frac{1}{2} S_9/(1-F_L)$

[LHCb-PAPER-2014-066, arXiv:1501.03038 - Submitted to JHEP]

Angular analysis of $B^0_d \to K^* e^+ e^-$ decays





Observable	Measurement	SM prediction[†]
$F_{\rm L}$	$+0.16 \pm 0.06 \pm 0.03$	$+0.10^{+0.11}_{-0.05}$
$A_{\rm T}^{(2)}$	$-0.23 \pm 0.23 \pm 0.05$	$0.03^{+0.05}_{-0.04}$
$A_{\rm T}^{\rm Re}$	$+0.10 \pm 0.18 \pm 0.05$	$-0.15^{+0.04}_{-0.03}$
$A_{\rm T}^{\rm Im}$	$+0.14 \pm 0.22 \pm 0.05$	$(-0.2^{+1.2}_{-1.2}) \times 10^{-4}$

- Measurements well in agreement with SM predictions
- Constraints on $C_7^{(\prime)}$ competitive with radiative decays

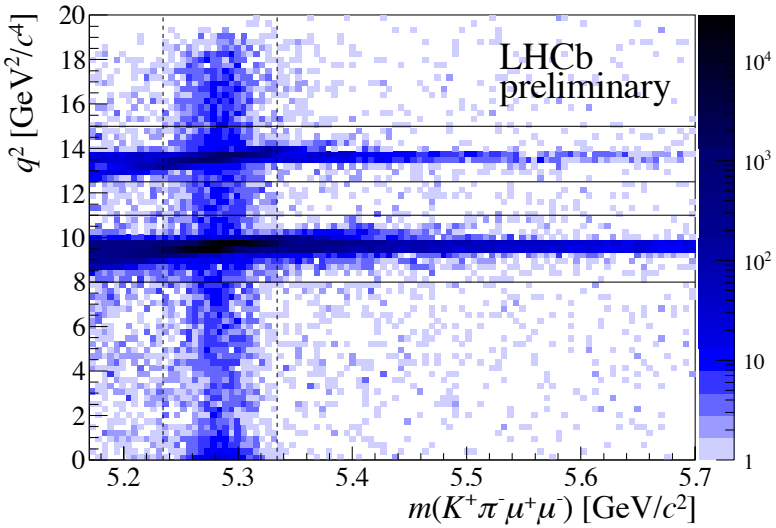
[†] S. Jäger, J. M. Camalich [arXiv/1412.3283]

[LHCb-PAPER-2014-066, arXiv:1501.03038 - Submitted to JHEP]

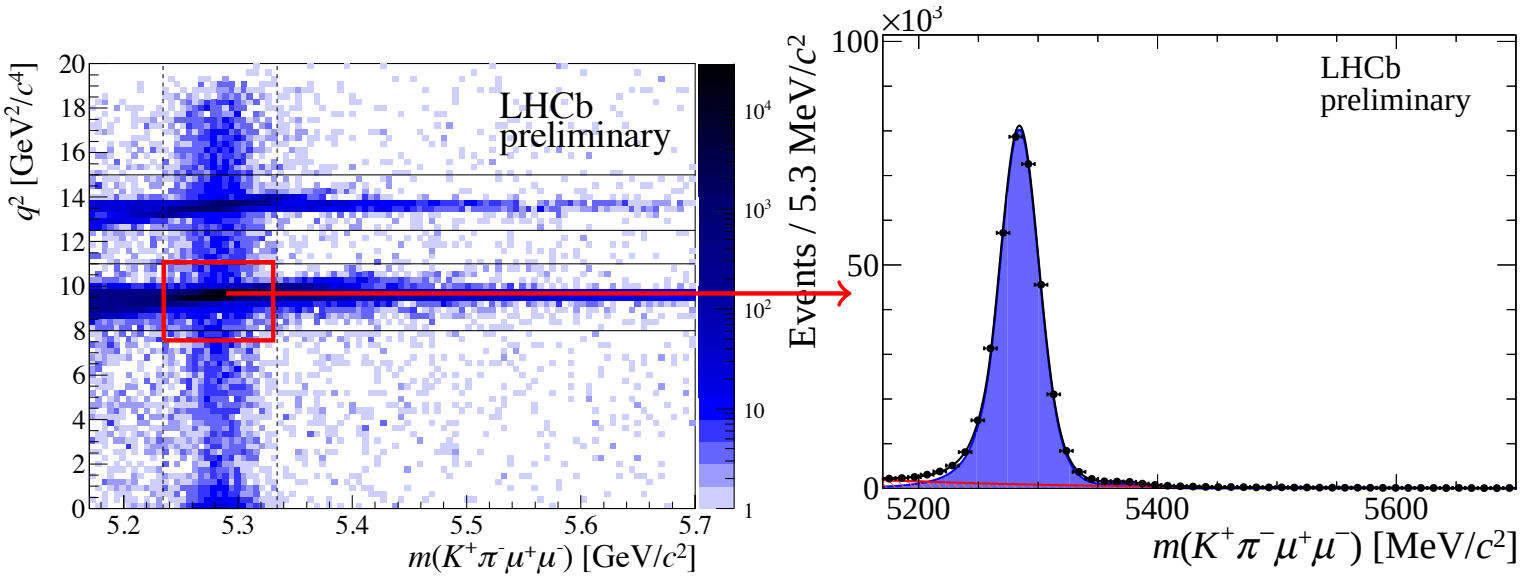
Angular analysis of the $B^0_d \to K^* \mu^+ \mu^-$ decay

[LHCb-CONF-2015-002]

Full Run I data update for a total luminosity of 3fb^{-1}

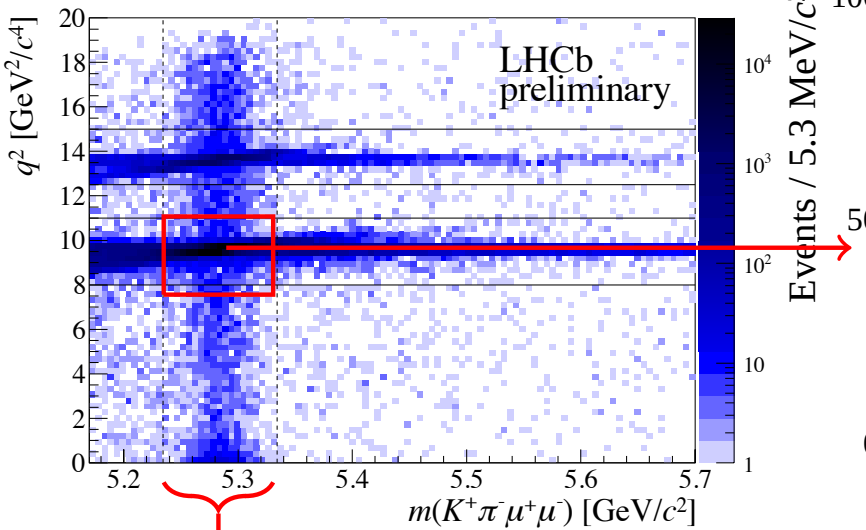


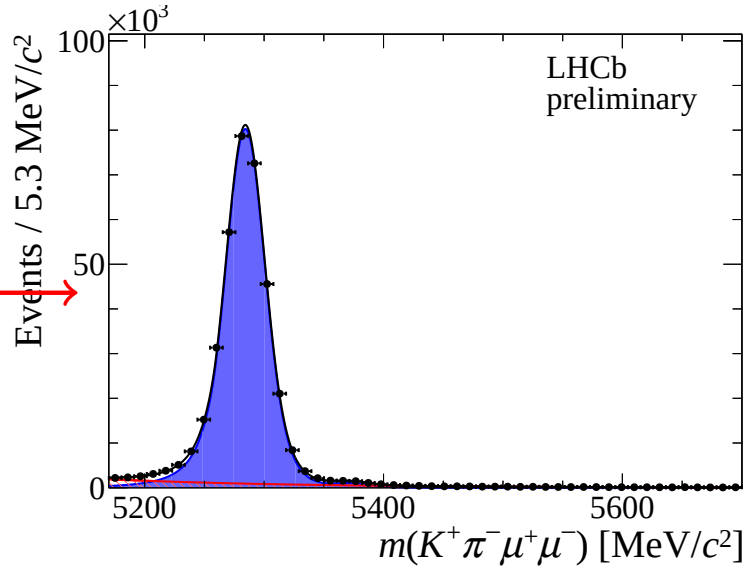
Angular analysis of the $B^0_d \to K^* \mu^+ \mu^-$ decay

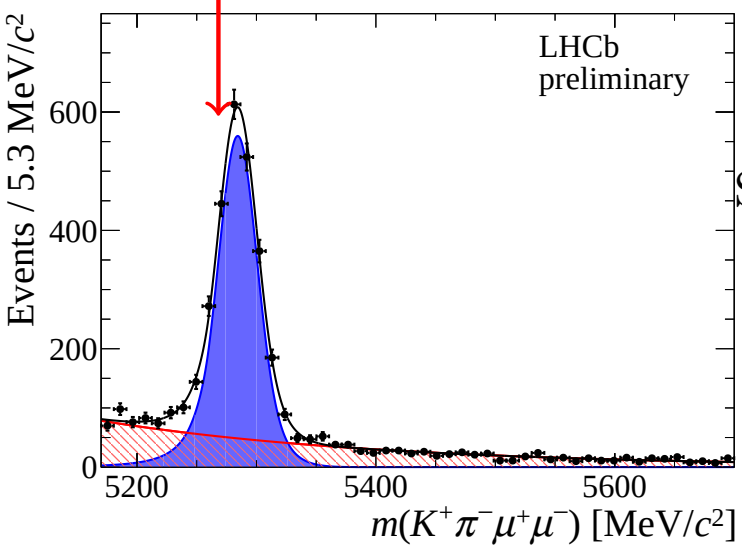


[LHCb-CONF-2015-002]

Angular analysis of the $B_d^0 \to K^* \mu^+ \mu^-$ decay







Selection

- BDT to reject combinatorial background
- Veto of resonant modes (used as control)

[LHCb-CONF-2015-002]

$B^0_d \to K^*\mu^+\mu^-$ likelihood fit

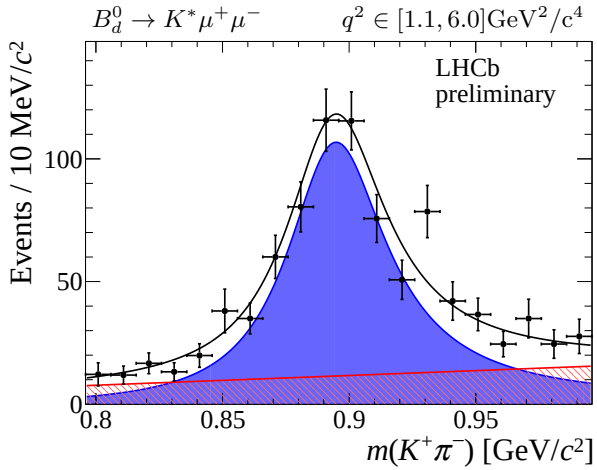
Angular analysis of the $B^0_d \to K^*\mu^+\mu^-$ decay

[LHCb-CONF-2015-002]

3fb^{-1} dataset allows improvements:

1. $K\pi$ S-wave component included by default (instead of systematic check):
   simultaneous fit to $K\pi$ mass

$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\tilde{\Omega}}\bigg|_{\mathrm{S+P}} = (1-F_{\mathrm{S}})\,\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\tilde{\Omega}}\bigg|_{\mathrm{P}} + \frac{3}{16\pi}F_{\mathrm{S}}\sin^2\theta_\ell \;+\; \text{S-P interference}$$



2. Full angular analysis: simultaneous determination of CP-averaged observables:
   Covariance matrix to be used for global fits

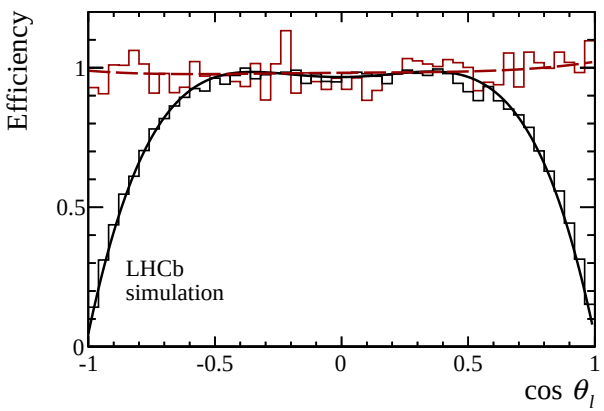
- Simultaneous fit of angular observables and mass in q^2 bins
- Background angular distribution modelled as 2^{nd} order Chebychev polynomials
- Feldman-Cousins procedure to estimate uncertainties

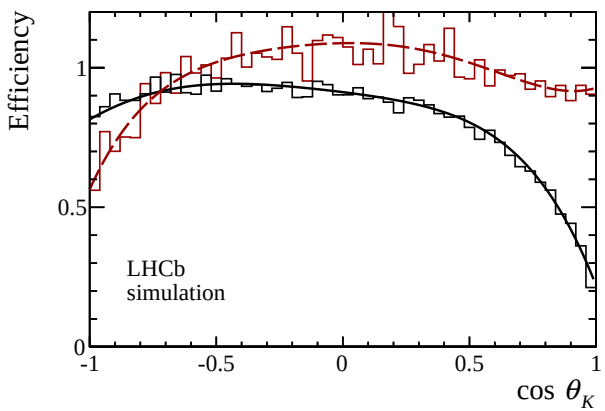
Acceptance effects

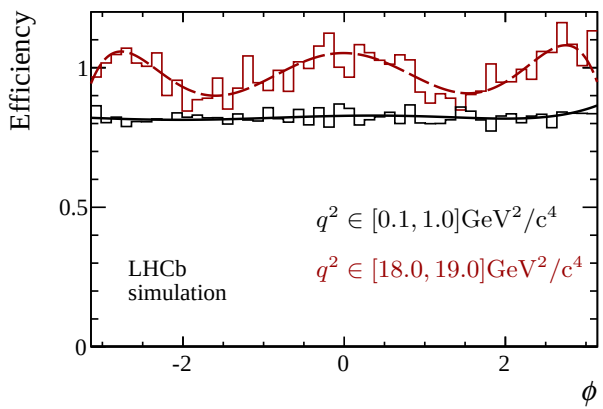
Angular analysis of the $B^0_d \to K^* \mu^+ \mu^-$ decay

[LHCb-CONF-2015-002]

- Acceptance, trigger and selection distort the angular distributions
- Efficiency parametrized in 4D using Legendre polynomials
- Coefficients from moment analysis of simulations
- Used as per-event weight or per bin correction depending on q^2 bin
- Cross-checked with $B^0_d \to K^* J/\psi$

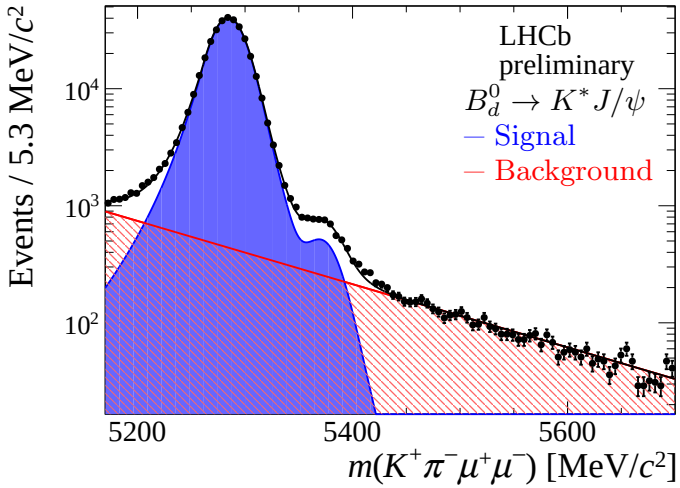


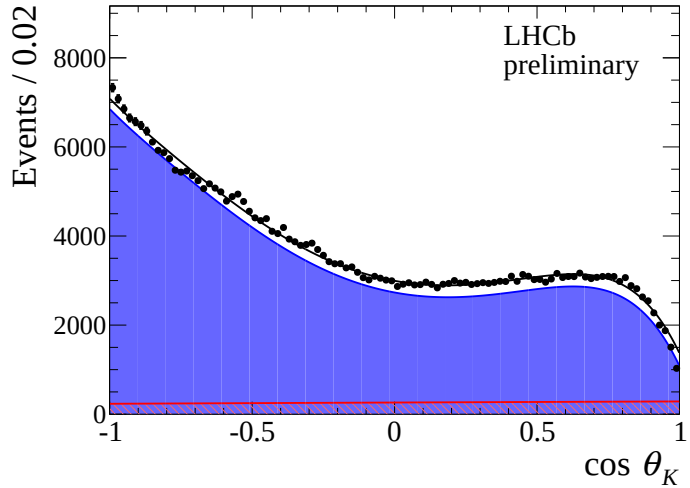


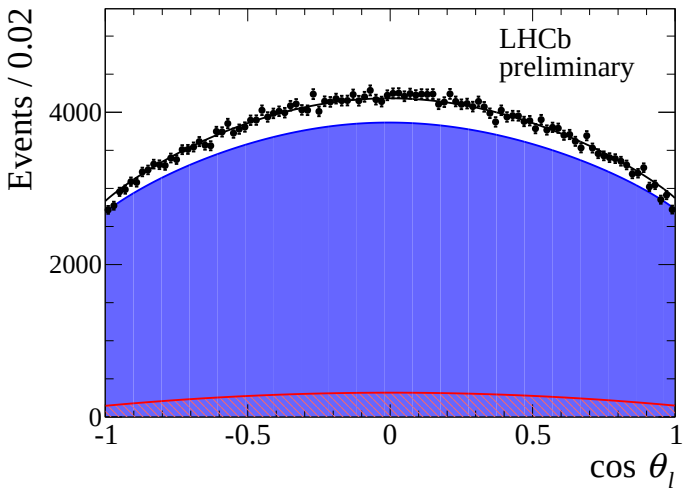


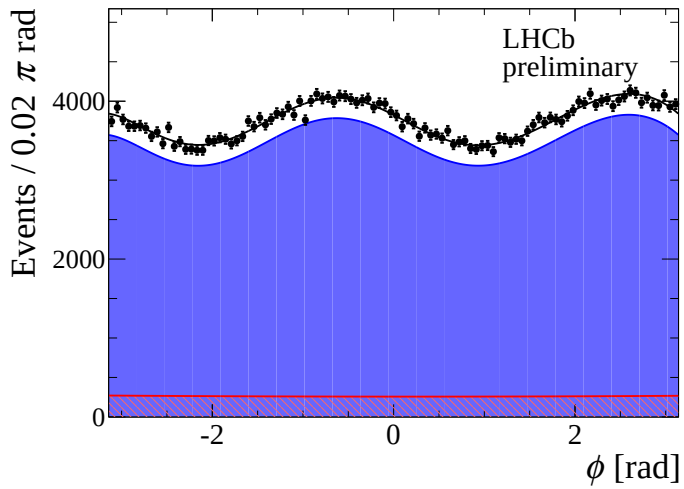
Fit to the control channel $B^0_d \to K^* J/\psi$

Angular analysis of the $B^0_d \to K^* \mu^+ \mu^-$ decay









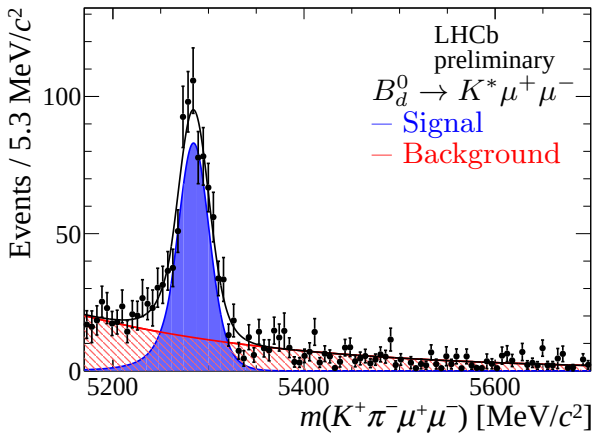
- Performed angular analysis of $B^0_d \to K^* J/\psi$
- Reproduced results of dedicated analysis [PRD 88, 052002 (2013)]

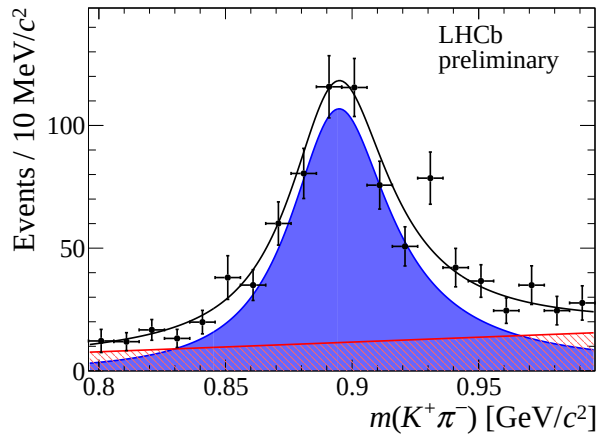
[LHCb-CONF-2015-002]

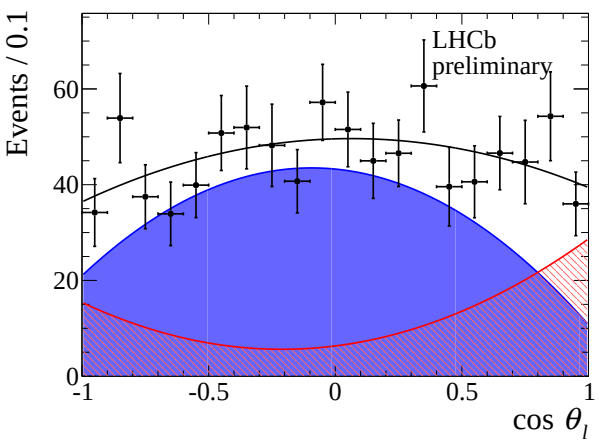
Results

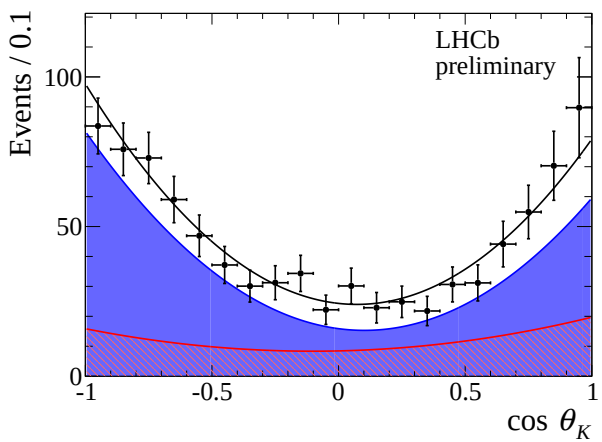
Angular analysis of the $B^0_d \to K^* \mu^+ \mu^-$ decay

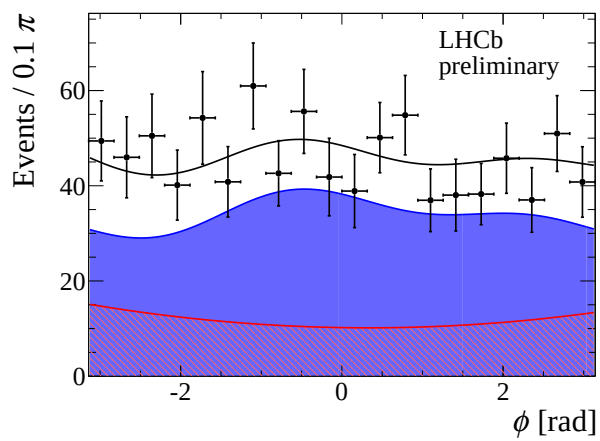
Projections of fit results for $q^2 \in [1.1, 6.0]\text{GeV}^2$
Good agreement of PDF projections with data in every bin of q^2
About 2400 events in the full q^2 range.







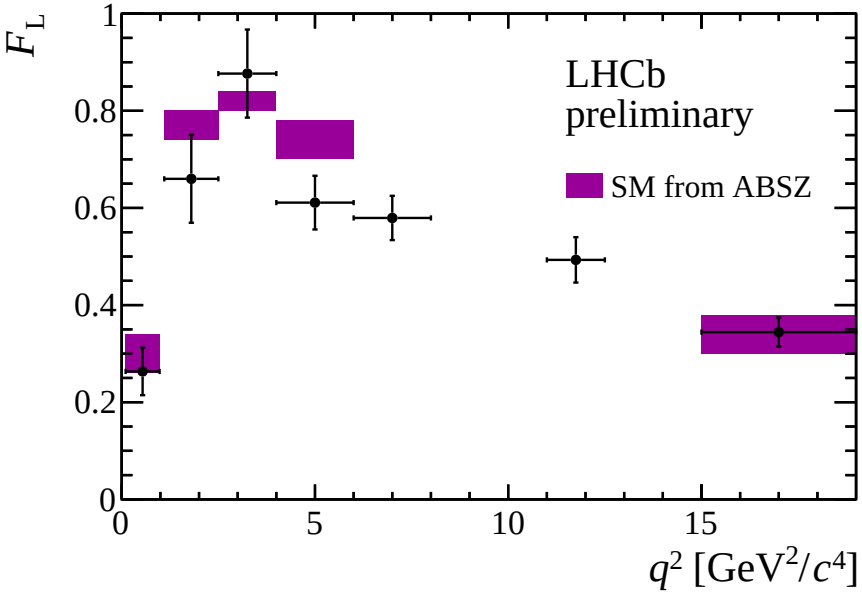


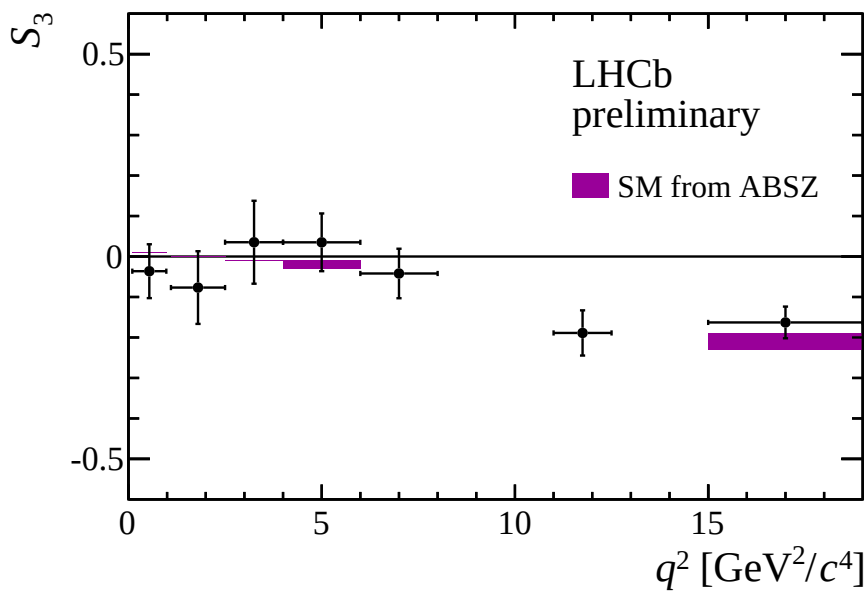


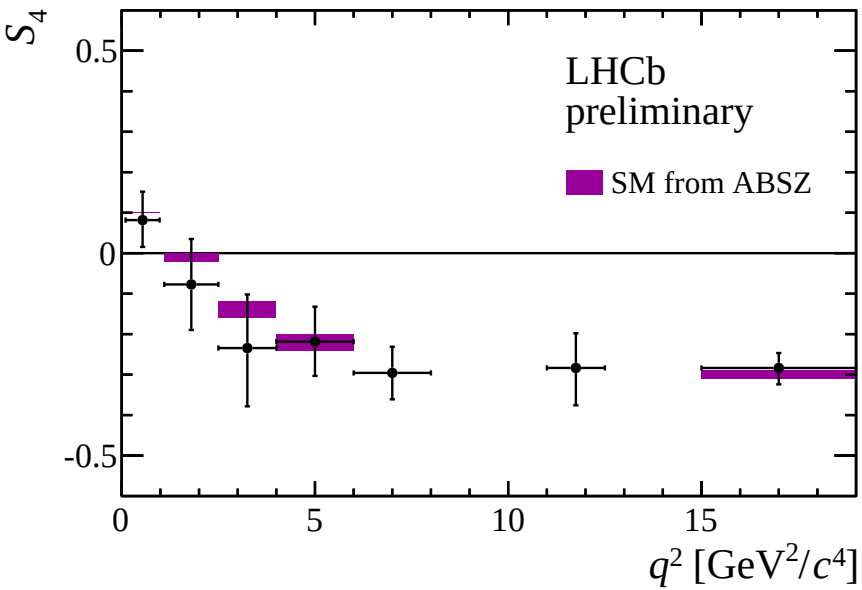
[LHCb-CONF-2015-002]

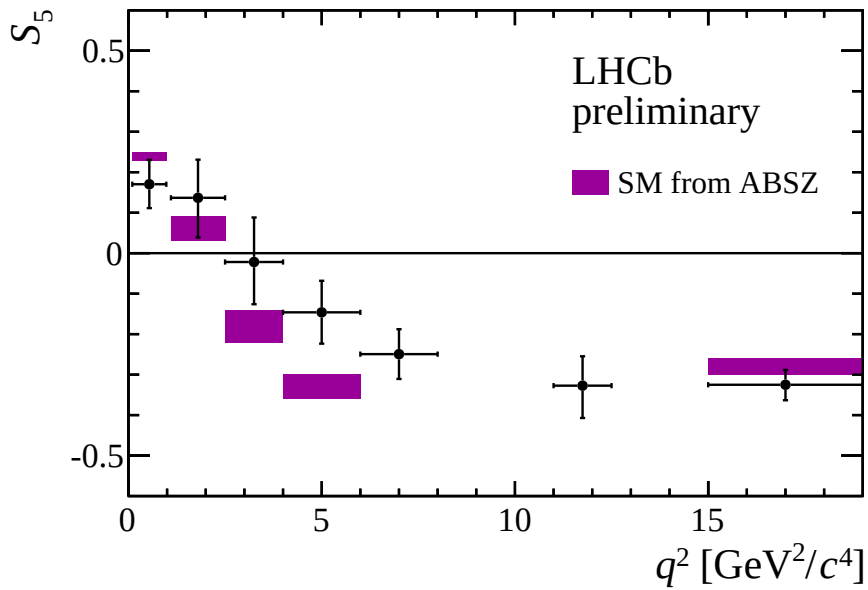
Results

Angular analysis of the $B^0_d \to K^* \mu^+ \mu^-$ decay





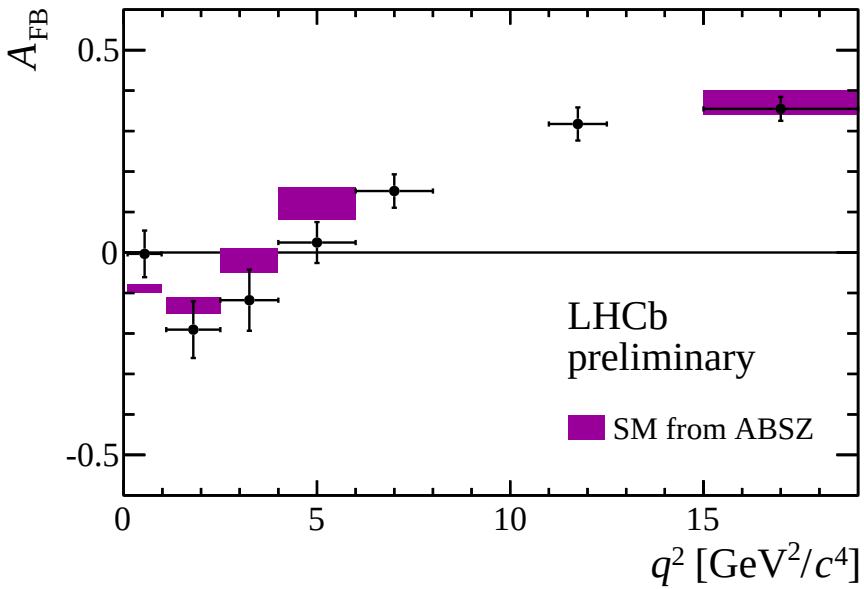


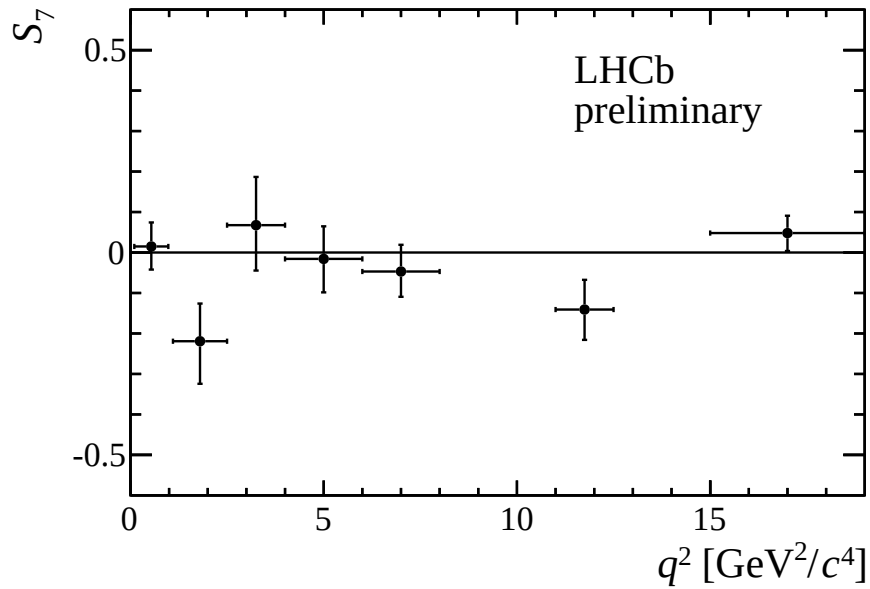


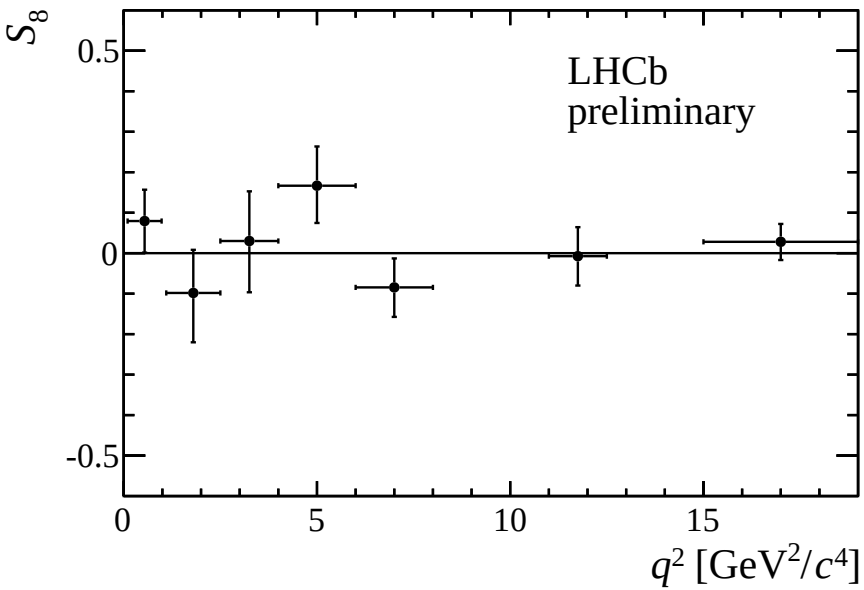
[LHCb-CONF-2015-002]

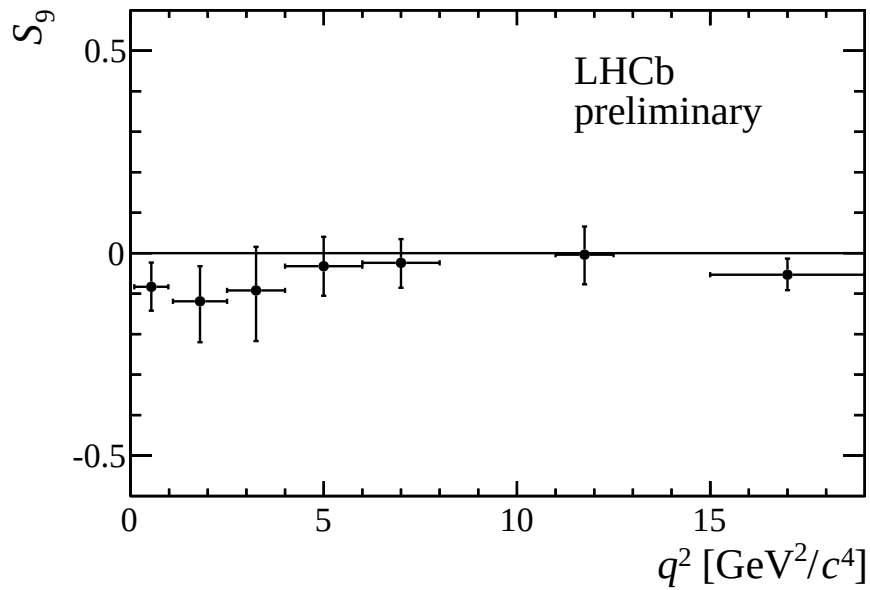
Results

Angular analysis of the $B_d^0 \to K^* \mu^+ \mu^-$ decay





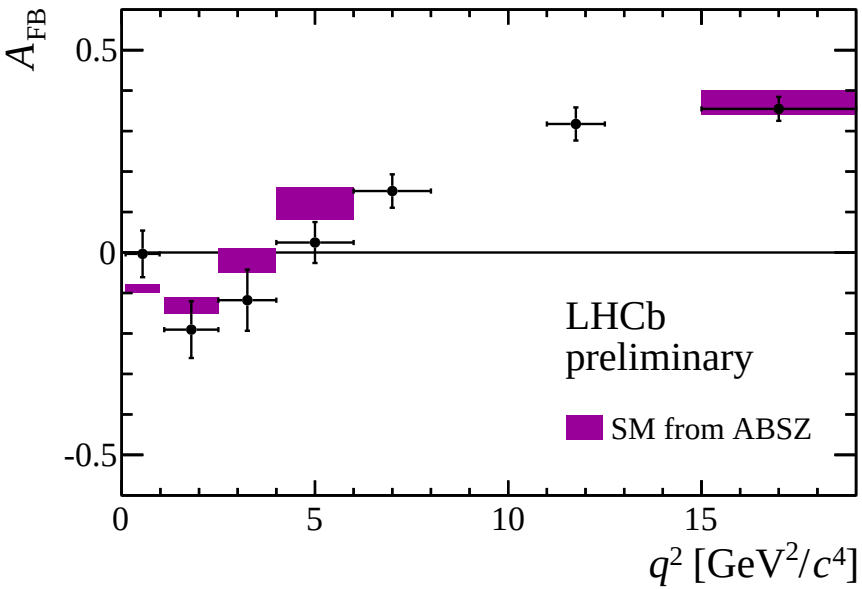




[LHCb-CONF-2015-002]

Results

Angular analysis of the $B^0_d \to K^* \mu^+ \mu^-$ decay



[LHCb-CONF-2015-002]

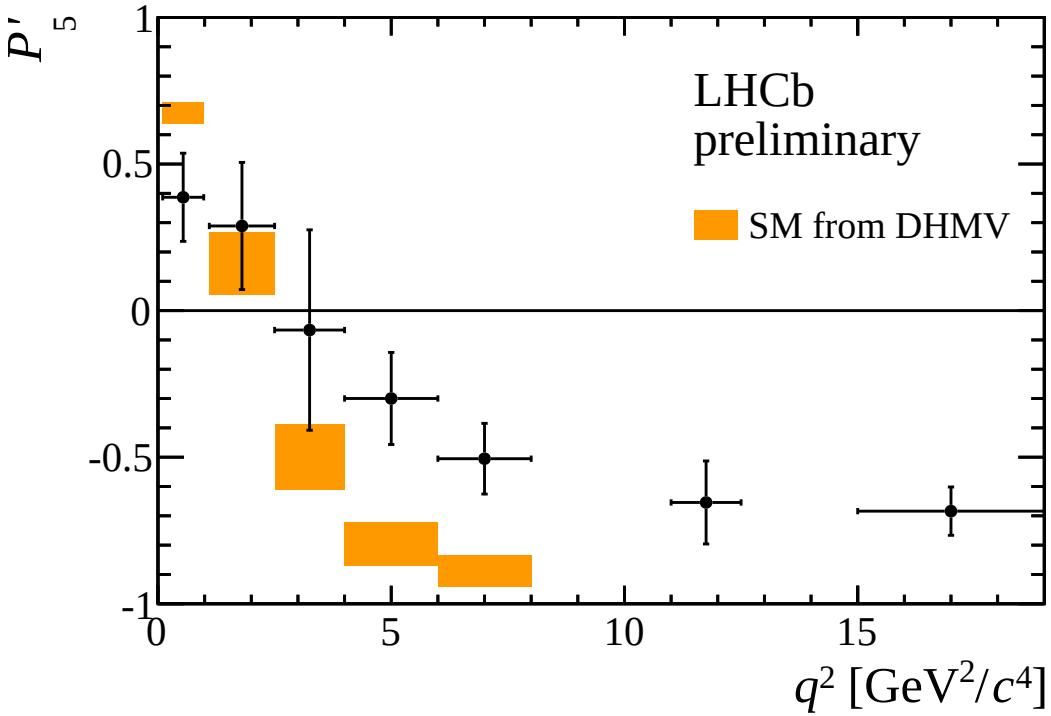
- Data points systematically lower than SM
- Measurement of zero-crossing point $q_0^2 = 3.7^{+0.8}_{-1.1}\text{GeV}^2$ evaluated as 1fb^{-1} analysis ([JHEP 08 (2013) 131])

† [SM from Bharucha et al, arXiv/1503.05534]

Results

Angular analysis of the $B^0_d \to K^* \mu^+ \mu^-$ decay

- Form-factor independent observables $P'_5 = \frac{S_5}{\sqrt{F_L(1-F_L)}}$



- Tension in P'_5 [PRL 111, 191802 (2013)] confirmed with 3fb^{-1}
- Local deviations of 2.9σ and 3.0σ for $q^2 \in [4.0, 6.0]$ and $6.0, 8.0\ GeV^2$
- Naive combination of the two gives local significance of 3.7σ
- Agreement with $1\ \text{fb}^{-1}$ result

[SM from Descotes-Genon et al. JHEP12(2014)125]

[LHCb-CONF-2015-002]

Conclusions

- Rare decays are excellent indirect probes of NP
- Presented latest results of LHCb in various channels
- General agreement with SM predictions is seen
- Tensions in various observables in different channels
- Still lacking a coherent NP explanation that includes all
- Many results not shown today and many others to come with RunI data... looking forward to start again!

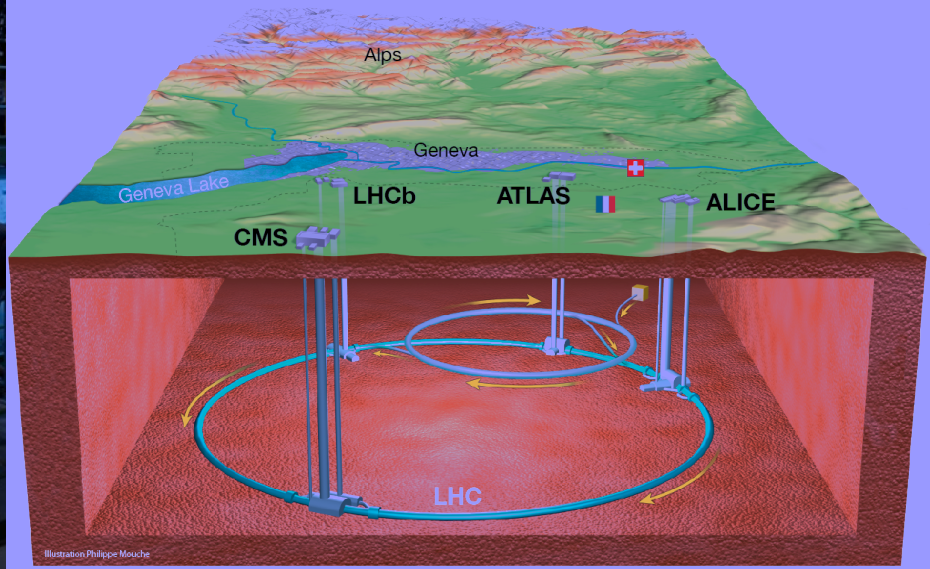
Rare decays at LHCb

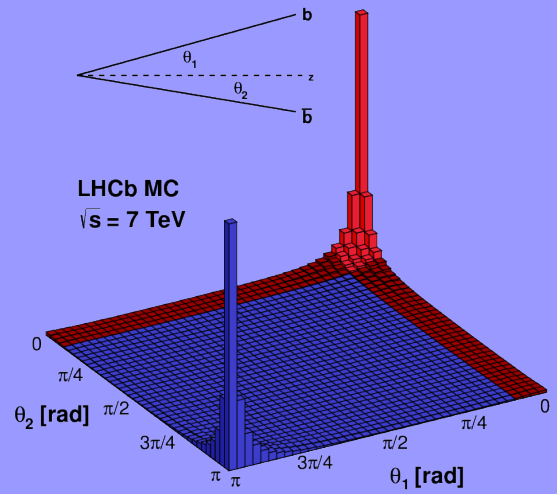
- Angular analysis of the $B^0 \to K^{*0} e^+ e^-$ decay in the low-q^2 region [LHCb, to appear in JHEP, arXiv:1501.03038]
- Study of the rare B_s^0 and B^0 decays into the $\pi^+\pi^-\mu^+\mu^-$ final state [LHCb, Phys. Lett. B743 (2015) 46, arXiv:1412.6433]
- Observation of the rare $B_s^0 \to \mu^+\mu^-$ decay from the combined analysis of CMS and LHCb data [CMS and LHCb, submitted to Nature, arXiv:1411.4413]
- Search for the lepton flavour violating decay $\tau^- \to \mu^-\mu^+\mu^-$ [LHCb, JHEP 02 (2015) 121, arXiv:1409.8548]
- First observations of the rare decays $B^+ \to K^+\pi^+\pi^-\mu^+\mu^-$ and $B^+ \to \phi K^+\mu^+\mu^-$ [LHCb, JHEP 10 (2014) 064, arXiv:1408.1137]
- Measurement of CP asymmetries in the decays $B^0 \to K^{*0}\mu^+\mu^-$ and $B^+ \to K^+\mu^+\mu^-$ [LHCb, JHEP 09 (2014) 177, arXiv:1408.0978]
- Test of lepton universality using $B^+ \to K^+\ell^+\ell^-$ decays [LHCb, Phys. Rev. Lett. 113 (2014) 151601, arXiv:1406.6482]
- Angular analysis of charged and neutral $B \to K\mu^+\mu^-$ decays [LHCb, JHEP 05 (2014) 082, arXiv:1403.8045]
- Differential branching fractions and isospin asymmetries of $B \to K^{(*)}\mu^+\mu^-$ decays [LHCb, JHEP 06 (2014) 133, arXiv:1403.8044]
- Observation of photon polarization in the $b \to s\gamma$ transition [LHCb, Phys. Rev. Lett. 112 (2014) 161801, arXiv:1402.6852]
- Search for Majorana neutrinos in $B^- \to \pi^+\mu^-\mu^-$ decays [LHCb, Phys. Rev. Lett. 112 (2014) 131802, arXiv:1401.5361]
- Measurement of CP violation in the phase space of $B^\pm \to K^+K^-\pi^\pm$ and $B^\pm \to \pi^+\pi^-\pi^\pm$ decays [LHCb, Phys. Rev. Lett. 112 (2014) 011801, arXiv:1310.4740]
- Search for the decay $D^0 \to \pi^+\pi^-\mu^+\mu^-$ [LHCb, Phys. Lett. B728 (2014) 234, arXiv:1310.2535]
- Measurement of form-factor-independent observables in the decay $B^0 \to K^{*0}\mu^+\mu^-$ [LHCb, Phys. Rev. Lett. 111 (2013) 191801, arXiv:1308.1707]
- Measurement of the CP asymmetry in $B^+ \to K^+\mu^+\mu^-$ decays [LHCb, Phys. Rev. Lett. 111 (2013) 151801, arXiv:1308.1340]
- Observation of a resonance in $B^+ \to K^+\mu^+\mu^-$ decays at low recoil [LHCb, Phys. Rev. Lett. 111 (2013) 112003, arXiv:1307.7595]
- Measurement of the $B_s^0 \to \mu^+\mu^-$ branching fraction and search for $B^0 \to \mu^+\mu^-$ decays at the LHCb experiment [LHCb, Phys. Rev. Lett. 111 (2013) 101805, arXiv:1307.5024]
- Search for the lepton-flavour-violating decays $B_s^0 \to e^\pm\mu^\mp$ and $B^0 \to e^\pm\mu^\mp$ [LHCb, Phys. Rev. Lett. 111 (2013) 141801, arXiv:1307.4889]
- Measurement of the differential branching fraction of the decay $\Lambda_b^0 \to \Lambda\mu^+\mu^-$ [LHCb, Phys. Lett. B725 (2013) 25, arXiv:1306.2577]
- Differential branching fraction and angular analysis of the decay $B_s^0 \to \phi\mu^+\mu^-$ [LHCb, JHEP 07 (2013) 084, arXiv:1305.2168]
- Search for the rare decay $D^0 \to \mu^+\mu^-$ [LHCb, Phys. Lett. B725 (2013) 15, arXiv:1305.5059]
- Measurement of the $B^0 \to K^{*0}e^+e^-$ branching fraction at low dilepton mass [LHCb, JHEP 05 (2013) 159, arXiv:1304.3035]
- Searches for violation of lepton flavour and baryon number in tau lepton decays at LHCb [LHCb, Phys. Lett. B724 (2013) 36, arXiv:1304.4518]
- Differential branching fraction and angular analysis of the decay $B^0 \to K^{*0}\mu^+\mu^-$ [LHCb, JHEP 08 (2013) 131, arXiv:1304.6325]
- Search for rare $B_{(s)}^0 \to \mu^+\mu^-\mu^+\mu^-$ decays [LHCb, Phys. Rev. Lett. 110 (2013) 211801, arXiv:1303.1092]
- First evidence for the decay $B_s^0 \to \mu^+\mu^-$ [LHCb, Phys. Rev. Lett. 110 (2013) 021801, arXiv:1211.2674]
- First observation of the decay $B^+ \to \pi^+\mu^+\mu^-$ [LHCb, JHEP 12 (2012) 125, arXiv:1210.2645]
- Measurement of the CP asymmetry in $B^0 \to K^{*0}\mu^+\mu^-$ decays [LHCb, Phys. Rev. Lett. 110 (2013) 031801, arXiv:1210.4492]
- Differential branching fraction and angular analysis of the $B^+ \to K^+\mu^+\mu^-$ decay [LHCb, JHEP 02 (2013) 105, arXiv:1209.4284]
- Search for the rare decay $K_S^0 \to \mu^+\mu^-$ [LHCb, JHEP 01 (2013) 090, arXiv:1209.4029]
- Measurement of the ratio of branching fractions $\mathcal{B}(B^0 \to K^{*0}\gamma)/\mathcal{B}(B_s^0 \to \phi\gamma)$ and the direct CP asymmetry in $B^0 \to K^{*0}\gamma$ [LHCb, Nucl. Phys. B867 (2013) 1-18, arXiv:1209.0313]
- Measurement of the isospin asymmetry in $B \to K^{(*)}\mu^+\mu^-$ decays [LHCb, JHEP 07 (2012) 133, arXiv:1205.3422]
- Strong constraints on the rare decays $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ [LHCb, Phys. Rev. Lett. 108 (2012) 231801, arXiv:1203.4493]
- Measurement of the ratio of branching fractions $\mathcal{B}(B^0 \to K^{*0}\gamma)/\mathcal{B}(B_s^0 \to \phi\gamma)$ [LHCb, Phys. Rev. D85 (2012) 112013, arXiv:1202.6267]
- Searches for Majorana neutrinos in B^- decays [LHCb, Phys. Rev. D85 (2012) 112004, arXiv:1201.5600]
- Differential branching fraction and angular analysis of the decay $B^0 \to K^{*0}\mu^+\mu^-$ [LHCb, Phys. Rev. Lett. 108 (2012) 181806, arXiv:1112.3515]
- Search for the rare decays $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ [LHCb, Phys. Lett. B708 (2012) 55, arXiv:1112.1600]
- Search for lepton number violating decays $B^+ \to \pi^-\mu^+\mu^+$ and $B^+ \to K^-\mu^+\mu^+$ [LHCb, Phys. Rev. Lett. 108 (2012) 101601, arXiv:1110.0730]

Additional material

LHCb experiment

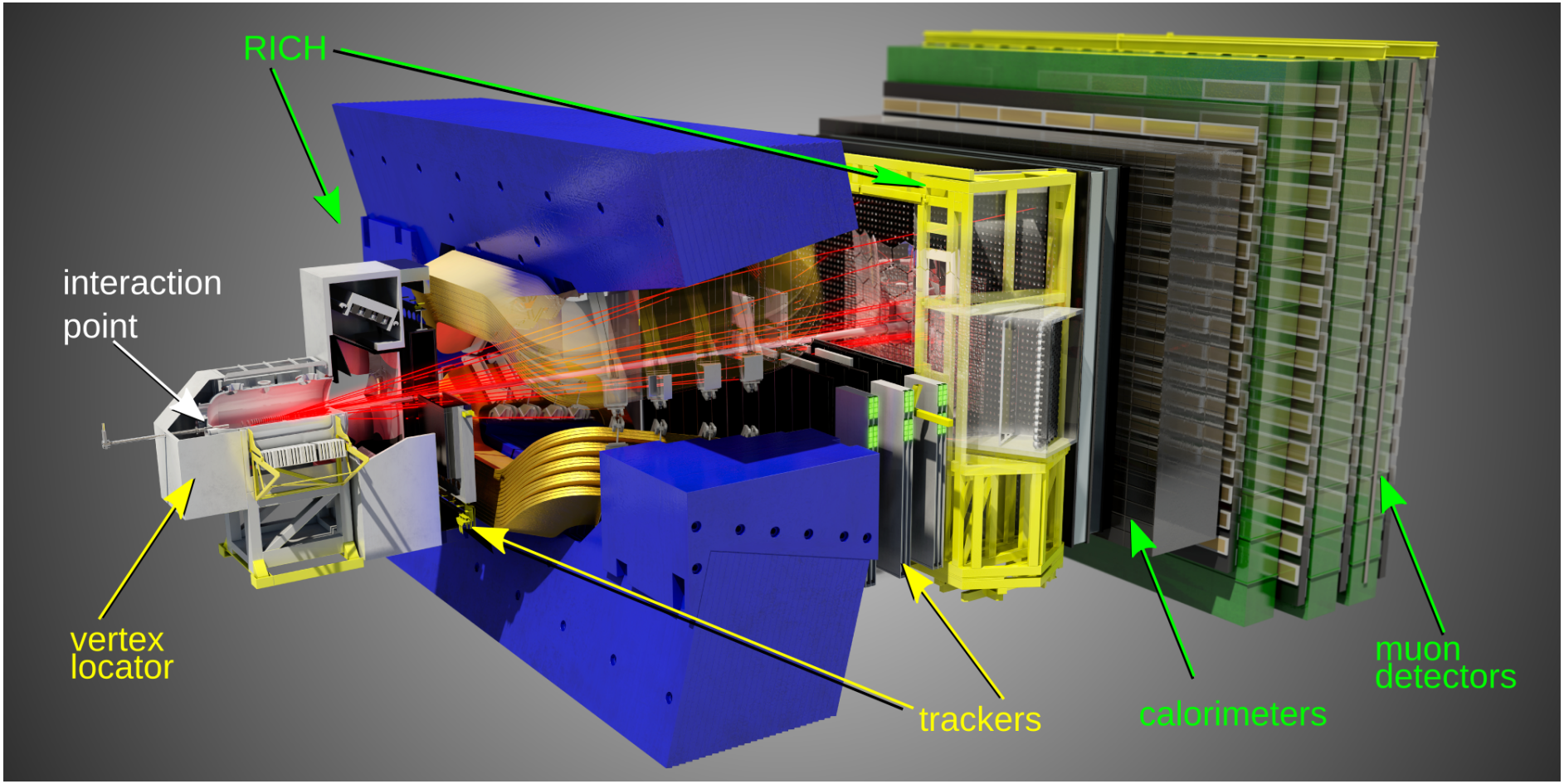
- 1075 members, from 68 institutes in 17 countries (September 2014)
- Dedicated experiment for precision measurements of CP violation and rare decays
- *Beautiful*, *charming*, *strange* physics program





- pp collisions at $\sqrt{s} = 8(13)$ TeV in RunI (RunII)
- $b\bar{b}$ quark pairs produced correlated in the forward region
- Luminosity of $4 \times 10^{32} cm^{-2} s^{-1}$

LHCb detector



Excellent vertex and IP resolution

- $\sigma(IP) \simeq 24\mu$m at $p_{\rm T} = 2$ GeV/c
- $\sigma_{\rm BV} \simeq 16\mu$m in x, y

Very good momentum resolution

- $\sigma(p)/p = 0.4\% - 0.6\%$ for $p \in (0, 100)$ GeV/c
- $\sigma(m_B) \sim 24$ MeV for two body decays

Muon identification

- $\varepsilon_\mu = 98\%$, $\varepsilon_{\pi\to\mu} = 0.6\%$, $\varepsilon_{K\to\mu} = 0.3\%$, $\varepsilon_{p\to\mu} = 0.3\%$

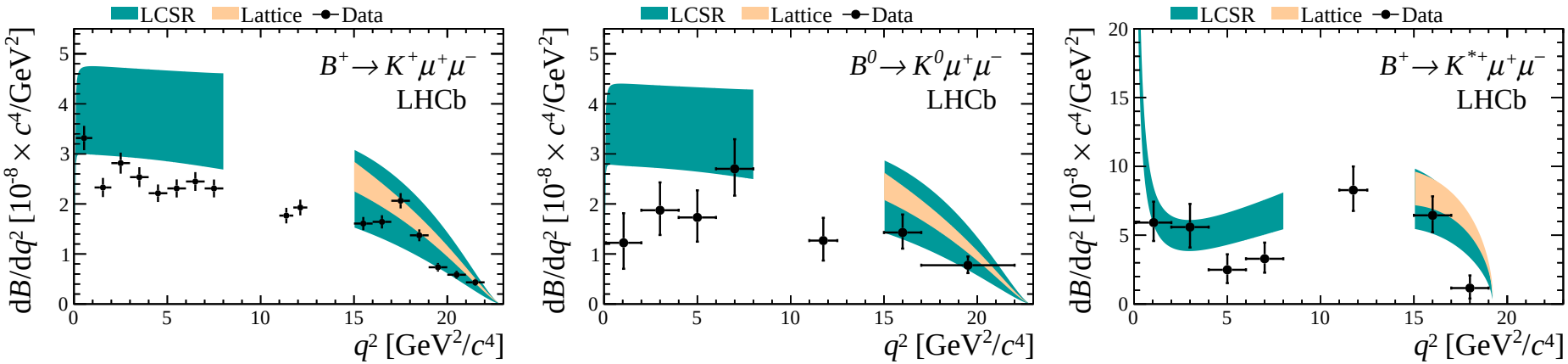
Trigger

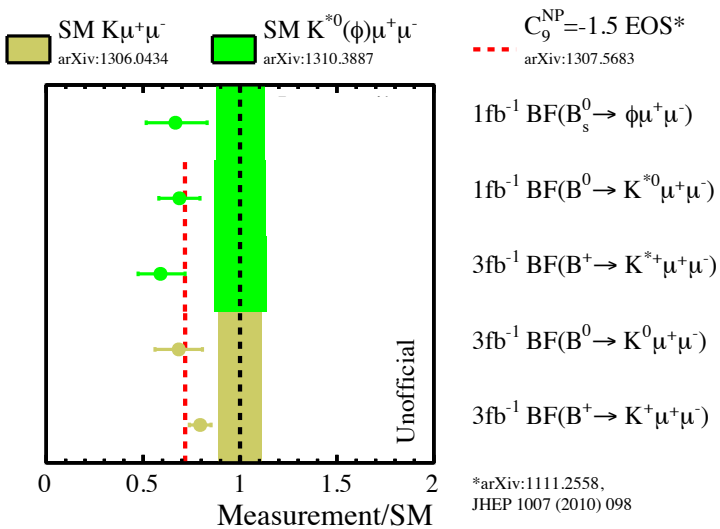
- $\varepsilon_\mu = 90\%$

Branching fractions

- Measurements of various $b \to s$ transitions systematically below the SM:
- Might be all due to modification of C_9

[JHEP 06 (2014) 133]

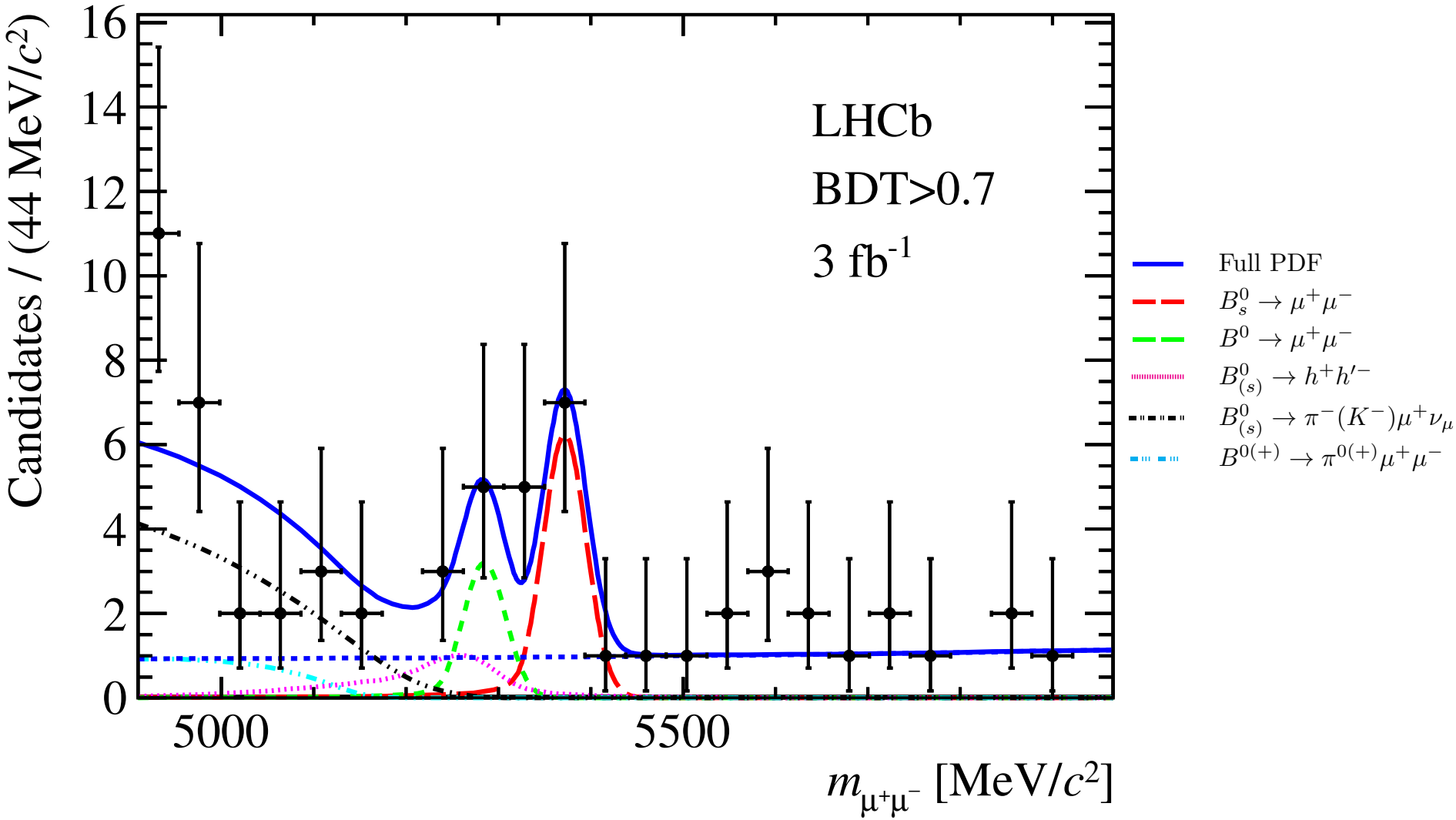




[JHEP 08 (2013) 131] [JHEP 06 (2014) 133] [JHEP 07 (2013) 084]

Opening the box

[Phys. Rev. Lett. 111, 101805 (2013)]



Results

[Phys. Rev. Lett. 111, 101805 (2013)]

The full fit gives the following central values

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = 2.9^{+1.1}_{-1.0}(stat)^{+0.3}_{-0.1}(syst) \times 10^{-9}$$

with a significance of 4.0σ

$$\mathcal{B}(B^0 \to \mu^+\mu^-) = 3.7^{+2.4}_{-2.1}(stat)^{+0.6}_{-0.4}(syst) \times 10^{-10}$$

with a significance of 2.0σ

- Systematic uncertainty obtained from total minus statistics (in quadrature)
- Plus additional component due to $\Lambda_b^0 \to p\mu^-\nu$ background
- Given no evidence of $B_s^0 \to \mu^+\mu^-$ the following upper limit has been put:

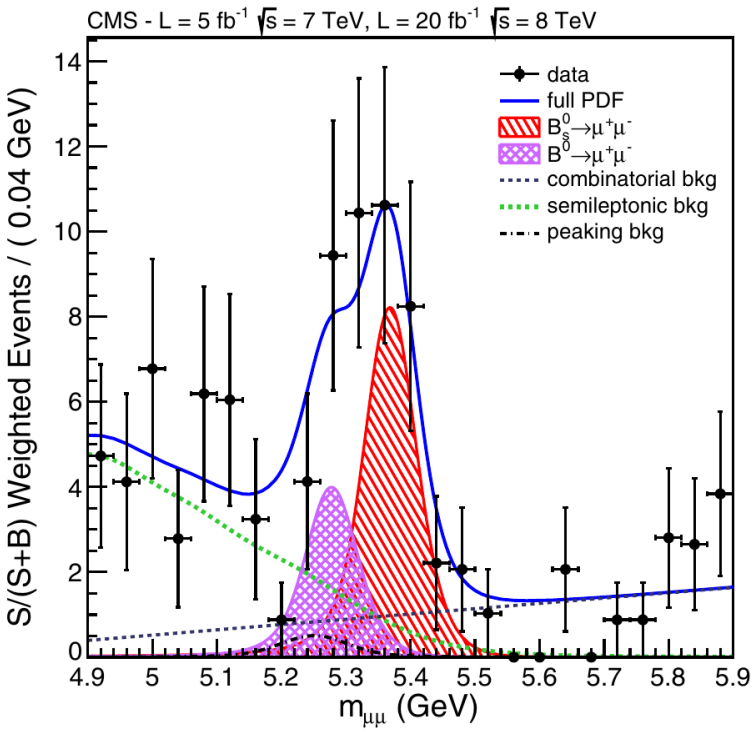
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 6.3(7.4) \times 10^{-10} \text{at } 90\ (95)\% \text{ CL}$$

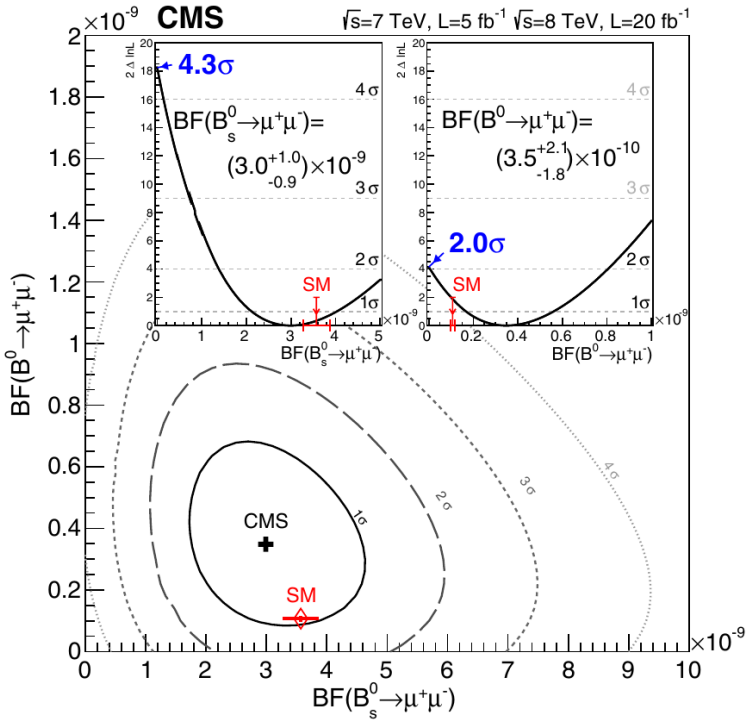
- First evidence of this decay obtained by LHCb in October 2012 with 2fb^{-1}
- Confirmed with higher significance in July 2013 with full Run I dataset

CMS results

[Phys. Rev. Lett. 111, 101804 (2013)]

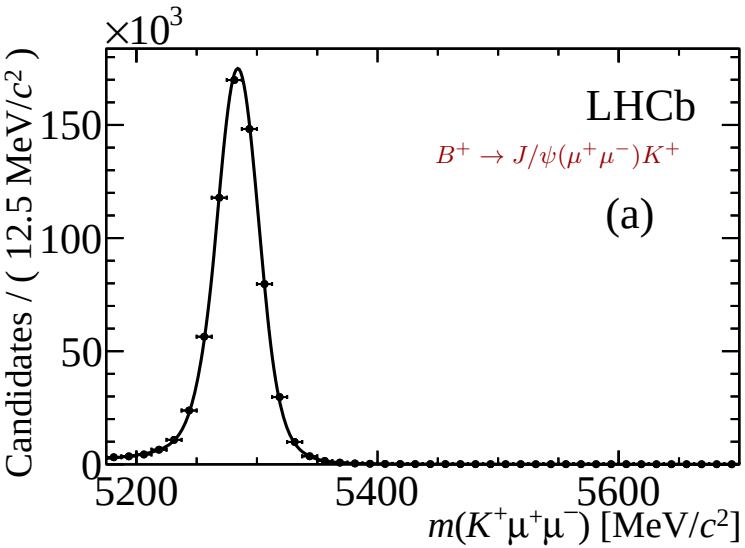
- Analysis of full Run I dataset (25 fb^{-1})
- 4.3 σ evidence of $B_s^0 \to \mu^+\mu^-$ with $\mathcal{B} = 3.0^{+1.0}_{-0.9} \cdot 10^{-9}$
- $B^0 \to \mu^+\mu^-$ significance of 2.0σ with $\mathcal{B} = 3.5^{+2.1}_{-1.8} \cdot 10^{-10}$

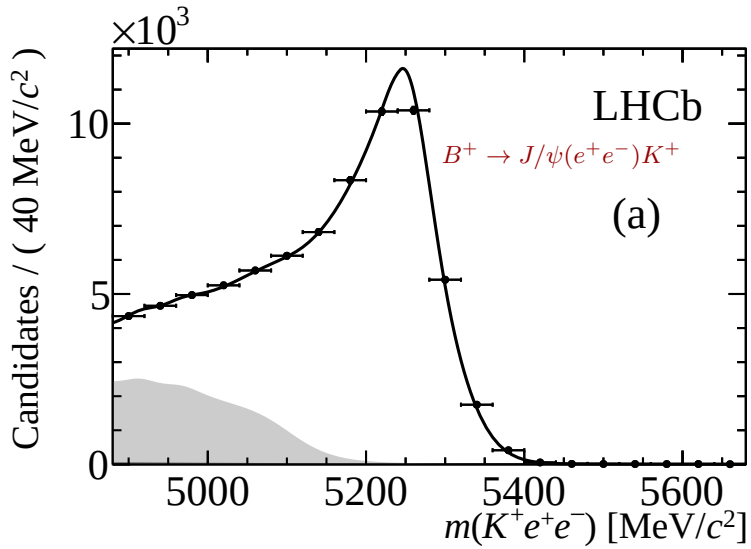




Test of lepton universality using $B^+ \to K^+\ell^+\ell^-$ decays

[Phys. Rev. Lett. 113, 151601]

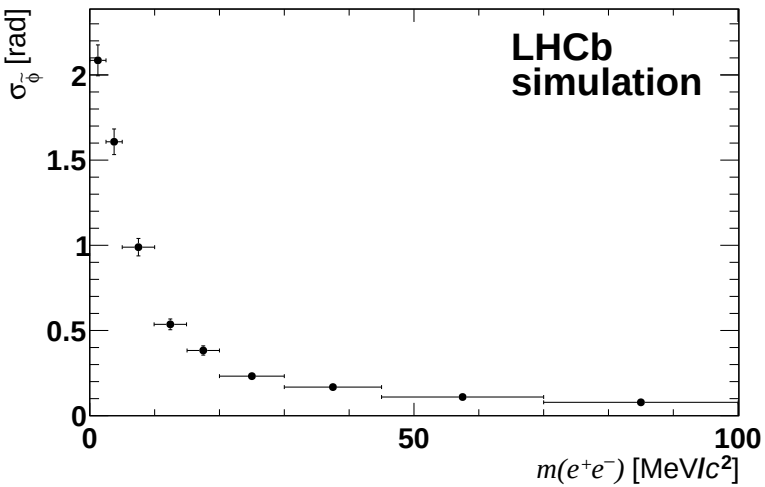




Angular analysis of $B^0_d \to K^* e^+ e^-$ decays

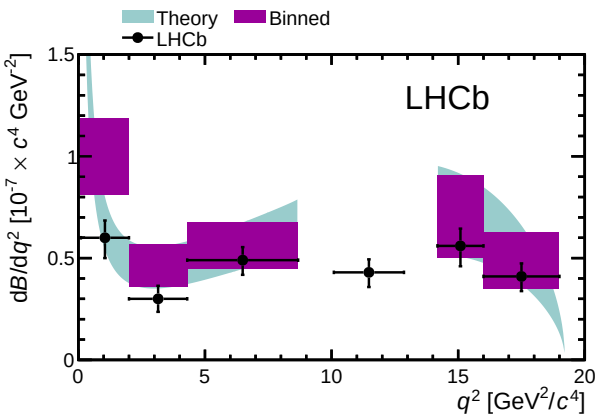
[LHCb-PAPER-2014-066, arXiv:1501.03038
Submitted to JHEP]

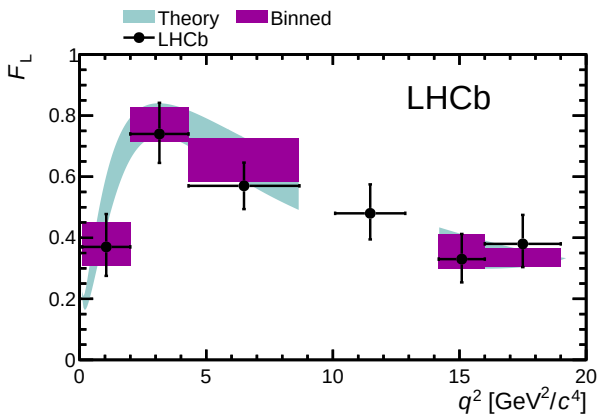
Resolution on the angle ϕ as a function of q^2

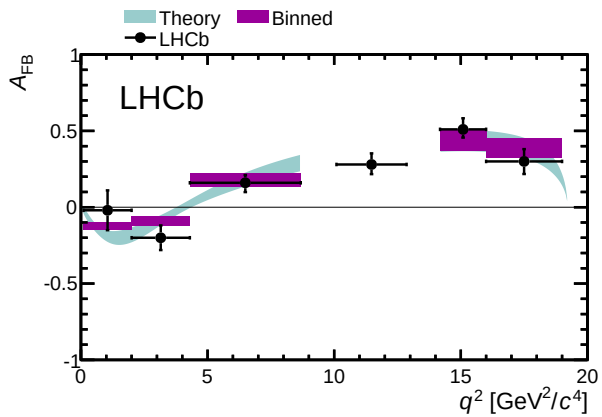


Angular analysis of the $B^0_d \to K^* \mu^+ \mu^-$ decay

1fb^{-1} analysis: [JHEP 1308 (2013) 131]

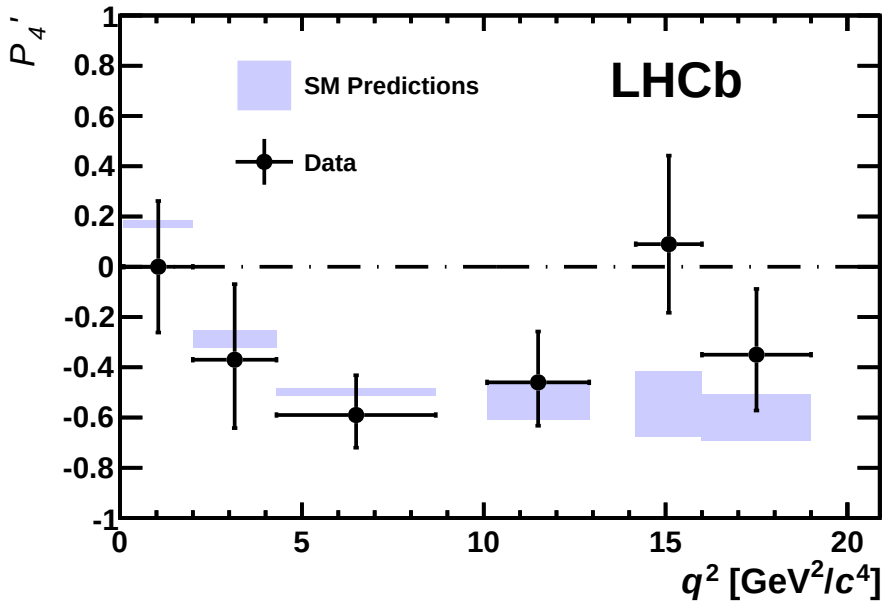


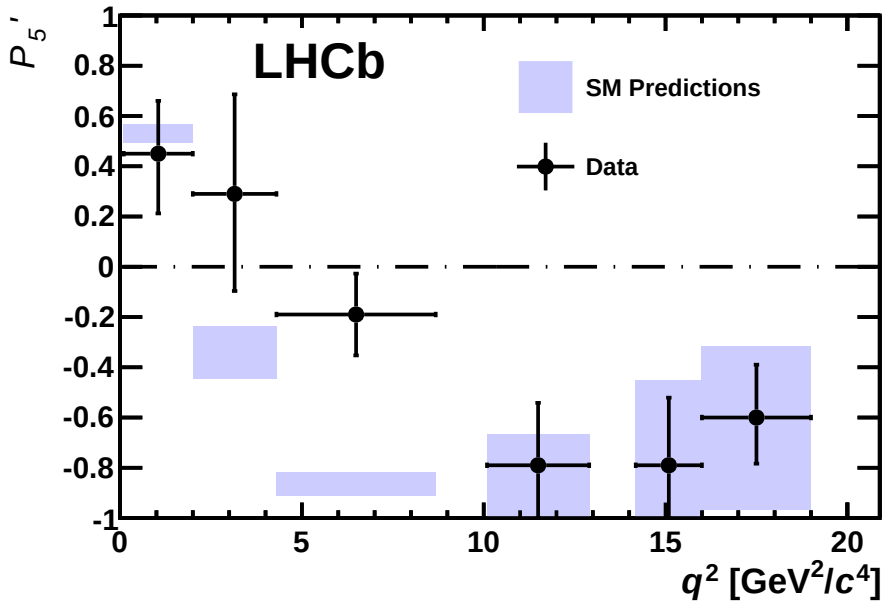




Angular analysis of the $B^0_d \to K^* \mu^+ \mu^-$ decay

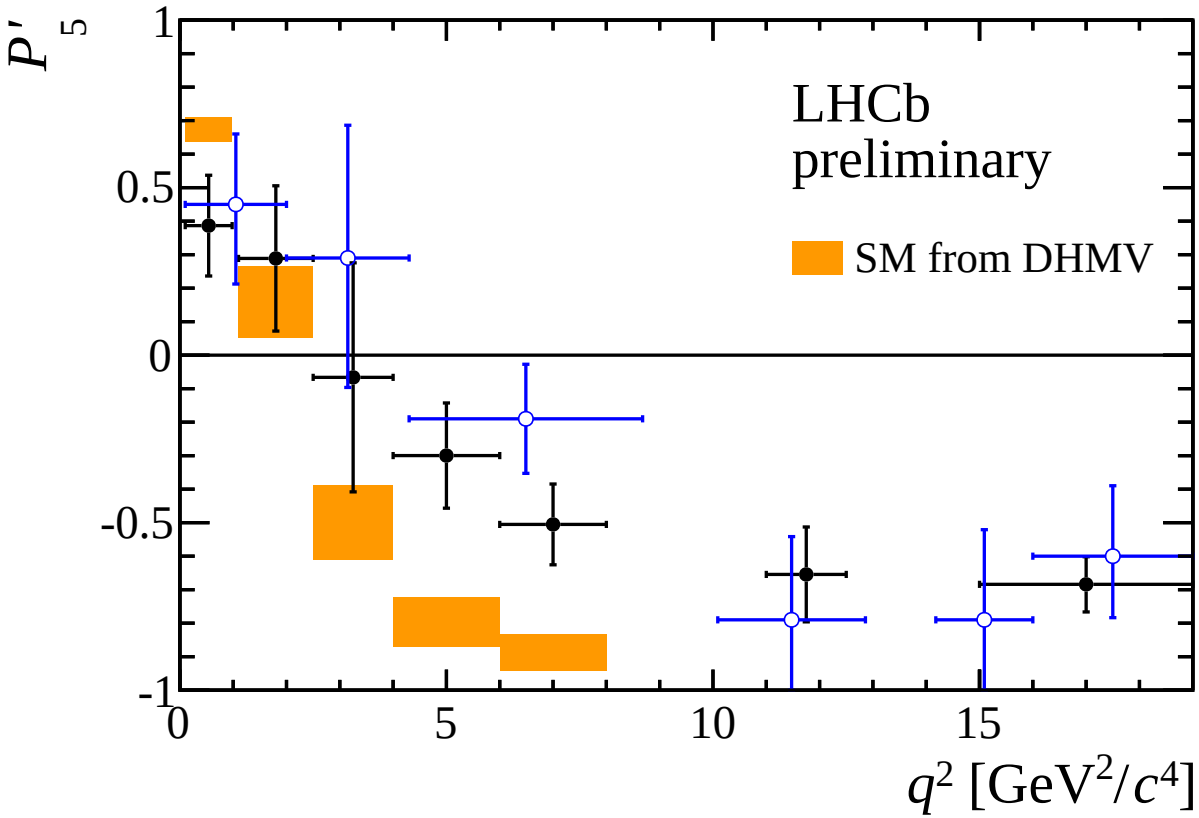
1fb^{-1} analysis - [Phys. Rev. Lett. 111, 191801 (2013)]





Angular analysis of the $B^0_d \to K^*\mu^+\mu^-$ decay

Comparison of 1fb^{-1} and 3fb^{-1} analysis

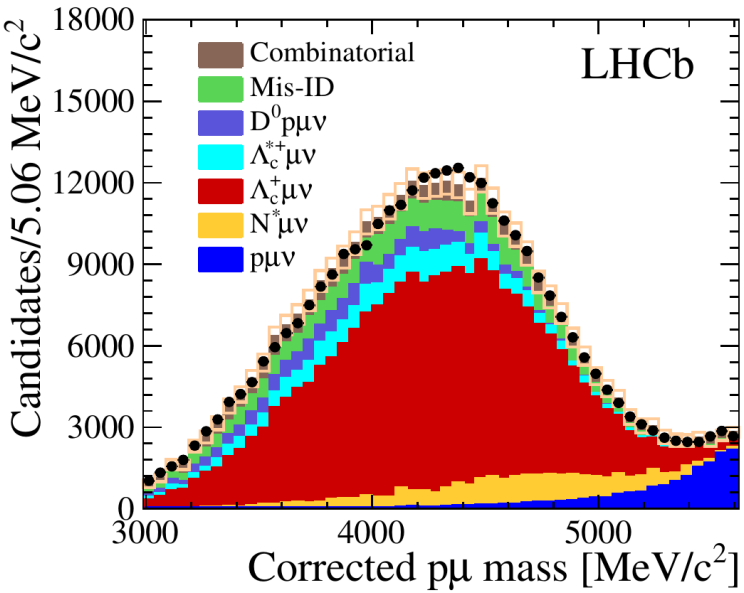


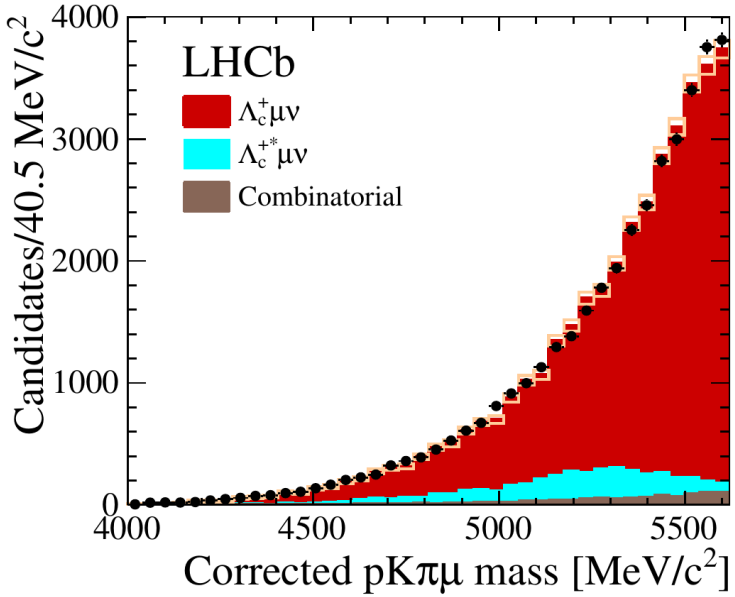
Angular analysis of the $B^0_d \to K^* \mu^+ \mu^-$ decay

Likelihood definition

$$\log \mathcal{L} = \sum_i \log \left[\epsilon(\vec{\Omega}, q^2) f_{\rm sig} \mathcal{P}_{\rm sig}(\vec{\Omega}) \mathcal{P}_{\rm sig}(m_{K\pi\mu\mu}) + (1 - f_{\rm sig}) \mathcal{P}_{\rm bkg}(\vec{\Omega}) \mathcal{P}_{\rm bkg}(m_{K\pi\mu\mu}) \right]$$
$$+ \sum_i \log \left[f_{\rm sig} \mathcal{P}_{\rm sig}(m_{K\pi}) + (1 - f_{\rm sig}) \mathcal{P}_{\rm bkg}(m_{K\pi}) \right]$$

First determination of $|V_{ub}|$ using the exclusive decay $\Lambda_b \to p\mu^-\bar{\nu}_\mu$





LHCb-PAPER-2015-013

- Normalized using $\Lambda_b \to \Lambda_c^+(pK\pi)\mu^-\bar{\nu}_\mu$
- Form factors predictions from lattice calculations
- Only high q^2 $(> 15GeV^2)$
- Corrected mass: $m_{corr} = \sqrt{m_{X\mu}^2 + p_\perp^2} + p_\perp$
- Using $|V_{cb}| = (39.5 \pm 0.8) \times 10^{-3}$ (from exclusive decays)
- Result

$$|V_{ub}| = (3.27 \pm 0.15 \pm 0.15 \pm 0.06) \times 10^{-3}$$